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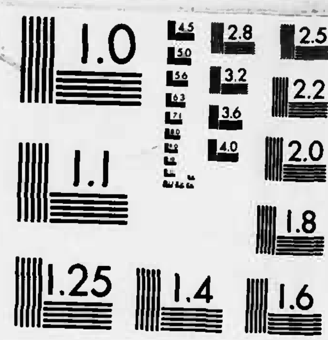

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A MODEL FOR WORLD WIDE FALLOUT IN THE NORTHERN HEMISPHERE

THESIS

Brian Grosner
Captain (P), USA

AFIT/GNE/ENP/85M-7

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A MODEL FOR WORLD WIDE FALLOUT IN THE NORTHERN HEMISPHERE

THESIS

Presented to the Faculty of the School of Engineering

of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the

Requirements for the Degree of

Master of Science in Nuclear Engineering

Brian Grosner, B.S.

Captain (P), USA

January 1985

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Preface

The purpose of this ~~report~~ Thesis was to develop a model that would predict world wide fallout in the northern hemisphere by modeling the stratospheric to tropospheric exchange processes. The method utilizes work by previous authors to calculate air mass flow in terms of mass flux at an average tropopause height. Inherent in the development of the model was to keep it simple enough to be programed into a personal or home computer.

The model ~~that was developed~~ is adaptable to the dispersion of ~~other~~ debris clouds that are made up of particles in the stratosphere, other than just those from nuclear detonations. (to p 92)

I thank Dr. D.J. Bridgman for his guidance and patience during the period of this thesis study. I also wish to acknowledge the assistance of the other graduate students at the Air Force Institute of Technology who provided assistance as needed, especially Captain Stephen Connors, USAF, for use of findings from his own thesis and Captain David Little, who provided much needed support. Finally, thanks to my wife for putting up with long hours and short tempers.

Brian Grosner

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Abstract

A method is presented to model world wide fallout in the northern hemisphere. The model consists of injecting a radioactive cloud into the stratosphere and allowing it to grow with time. As the cloud reaches the tropopause it is injected to the troposphere using an air mass flux which is a function of latitude and season. The model is dependent on the assumed particle size distribution of the cloud. The model, using two particle size distributions that have been postulated, is compared to an empirical model based on the 1958 nuclear tests of the U.S. and U.S.S.R.

A MODEL FOR WORLD WIDE FALLOUT
IN THE NORTHERN HEMISPHERE

I. Introduction

Background

The ability to predict the spread and fall of the particles that make up the fallout generated from the detonations of nuclear weapons has recently been given additional importance due to the increased interest in nuclear winter studies (18). Since the prediction of world wide fallout basically consists of the tracking of particles as they are dispersed in the atmosphere, the methods should be adaptable to particles from other sources than just nuclear weapons.

Attempts to model world wide fallout generally use one of three methods. First is to develop a model that attempts to model all the physics involved. An example of such a model for local fallout prediction is the Defense Land Fallout Information Code (DELFIC). The drawback of these type models is that they require large computer codes and large computers to do the calculations. The second type of model utilizes empirical fits to experimental data from weapons tests to develop patterns of fall that can be used to predict subsequent tests. An example of such a model is presented in (15). The drawback of such a model is the output may be limited by the experimental data used for the patterns. The third type of model attempts to solve the diffusion equation for the fallout particles as they diffuse throughout the atmosphere.

Ernest Bauer has done work in this area (1;3;19). The extreme variability of the atmosphere, by season, latitude and altitude makes this an extremely complex problem.

The observed patterns of world wide fallout show that the fallout does not fall uniformly over the earth. The fall varies considerably by season (13) and by latitude (15). This is different from local fallout which generally falls in contiguous patterns of decreasing dose in the direction of the prevailing surface wind (6).

World wide fallout is defined in The Effects of Nuclear Weapons as "the smaller particles which ascend into the upper troposphere and into the stratosphere and are carried by the winds to all parts of the earth" (11:633). Thus any model which attempts to predict the world wide fall-out must take into account, in some manner, the winds of the upper tropo-sphere and stratosphere. The work of such researchers as Ernest Bauer, Elmar R. Reiter and J.F. Louis show that it is the influence of winds on the transfer of particles between the stratosphere and troposphere that dominates the rate of return to the ground (1;2;3;17;19).

Problem

This study attempts to model world wide fallout by modeling the stratospheric to tropospheric exchange processes in order to predict the amount of fallout transferred to the troposphere and subsequently to the ground.

Scope

In this study several limits on the model are implemented. The model only considers injections and fall of particles in the northern

hemisphere. Any transport of fallout across the equator is ignored. The range of bursts considered is from 1 to 10 megatons. The model considers only single burst injections.

General Approach

The model is based on the injection of a cloud of radioactive debris into the stratosphere. A tracer (Strontium 90) is used to track the growth of the radioactive cloud and subsequent deposition. As the cloud reaches the tropopause it is transferred across the tropopause using mass fluxes of air, with the accompanying fallout. These mass fluxes are developed from the vertical winds. Fall to the ground is assumed to take place in a time period small compared to the time period of the total fall, or is modeled as an exponential function.

Sequence of Presention

The report first discusses the atmosphere and the forces that affect the fallout. The next chapter discusses the model and how these forces are integrated into the computer code to predict fallout. Chapter IV discusses the empirical model of Kendell R. Peterson (15) which is used as a comparison for the model output. Chapter V compares and discusses the model output with the expected output. Finally Chapter VI makes conclusions and recommendations concerning the model.

II. Atmospheric Theory

The Atmosphere

The regions of the atmosphere that are important to the study of world wide fallout are the troposphere, tropopause and stratosphere (see Figure 1). The troposphere is the region immediately above the earth's surface. The height of the troposphere varies by latitude and season, as seen in Figures 2a-d. The top boundary of the troposphere is the tropopause. For the model presented in this report the tropopause is viewed as a line separating the two regions with an altitude of 12 km. This represents an average value for all seasons and latitudes. The stratospheric region extends from the tropopause up to approximately 52 km (17).

Almost all of the earth's weather occurs within the troposphere. This weather makes the troposphere much less stable than the stratosphere.

```
-------------------------------------------------   52 km

                   STRATOSPHERE

---------------------- Tropopause --------------   12 km

                   TROPOSPHERE

----------------- Surface of the Earth ----------    0 km
```

Figure 1. The Atmosphere

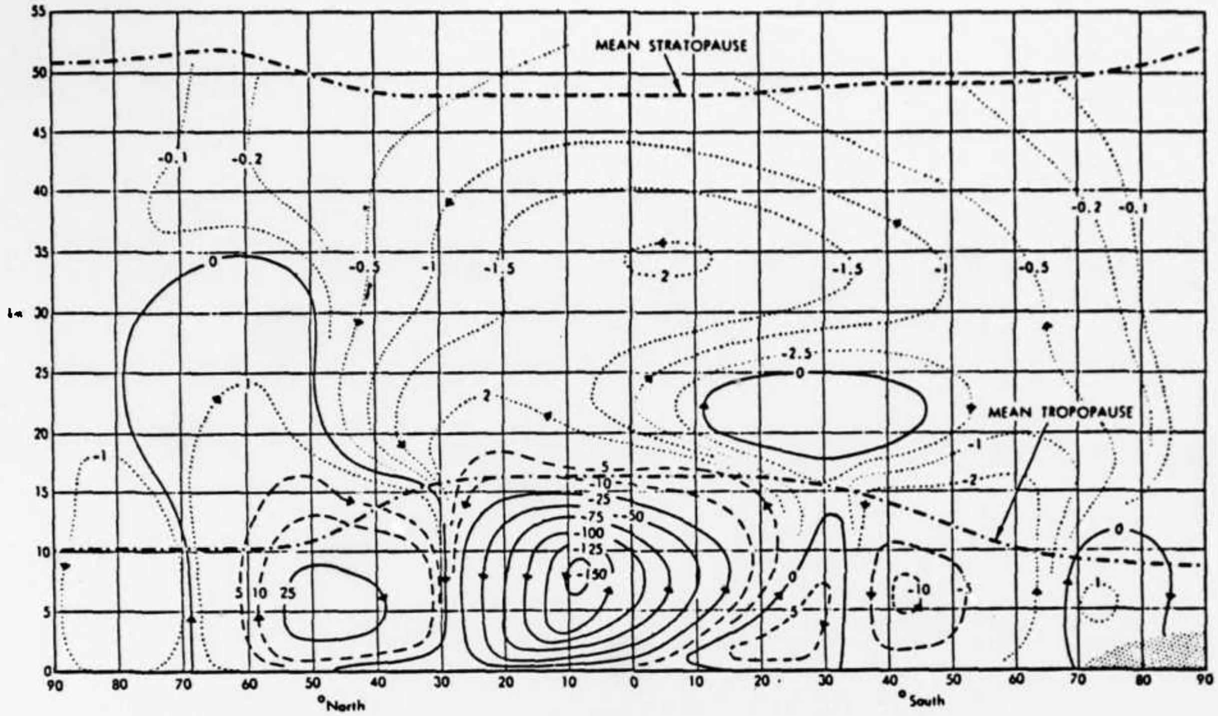

Figure 2a. December - February

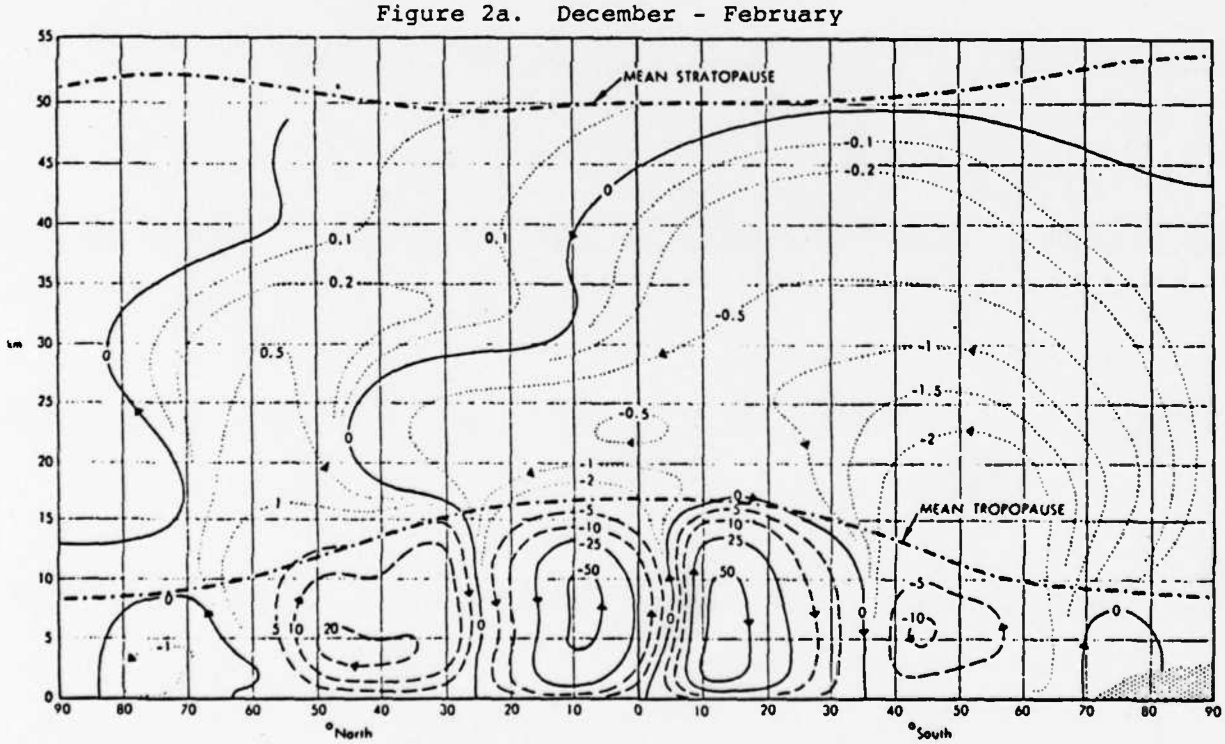

Figure 2b. March - May

Figure 2. Mean Meridional Circulation (10^{12} g/sec) From (17:463-464)

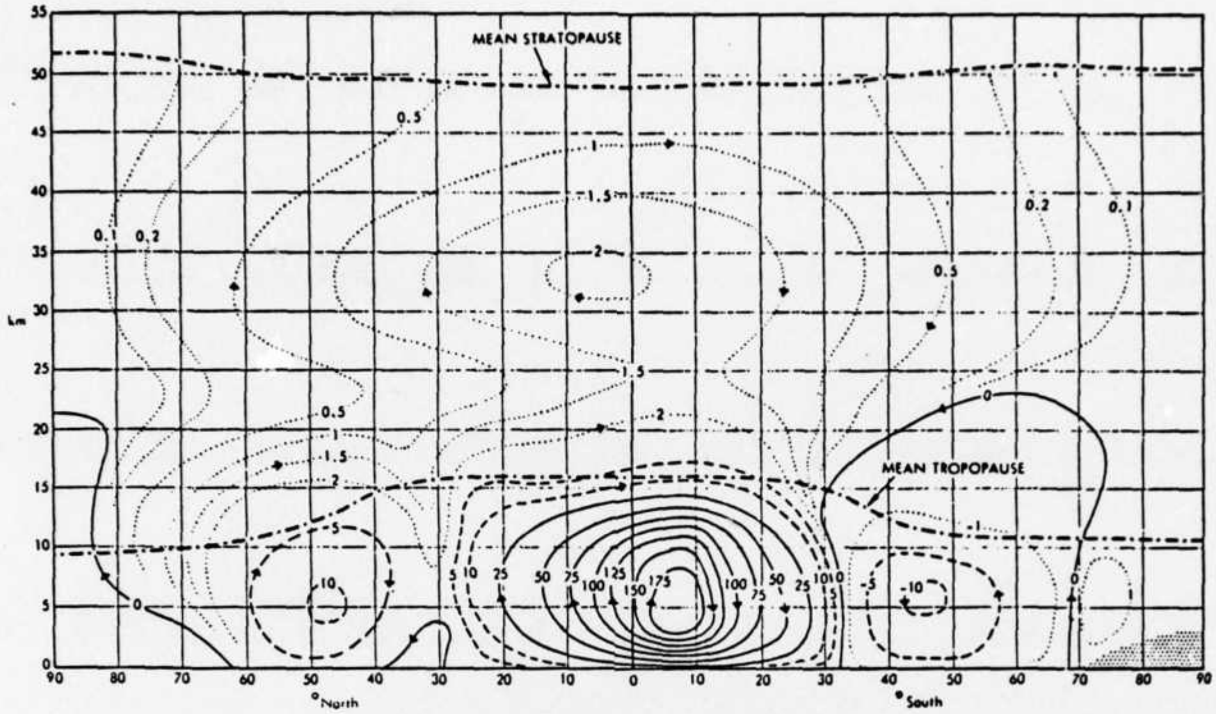

Figure 2c. June - August

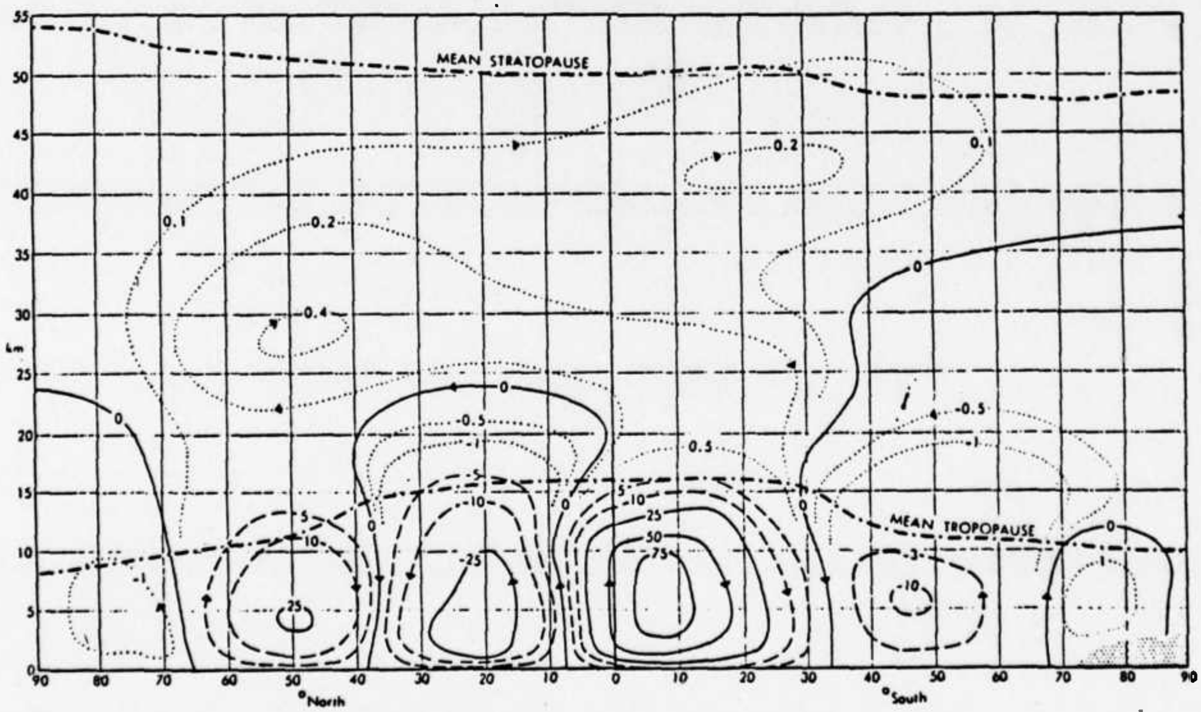

Figure 2d. September - November

Atmospheric Dynamics

The stratospheric to tropospheric exchange processes are critical to the understanding of the transport of particles across the tropopause. This transport is the reason that fallout particles fall back to earth faster than would be expected if only gravitational forces were in effect. This will be discussed later in the discussion of gravitational fall. For now, the assumption is made that there is "strong evidence for a continuous and rather effective exchange of air masses between troposphere and stratosphere" (17:459). Elmar R. Reiter identifies four processes that cause this exchange:

(1) seasonal adjustments in the height of the mean tropopause level;
(2) organized large-scale quasi-horizontal and vertical motions expressed by the mean meridional circulation;
(3) large-scale eddy transports, mainly in the jet stream region;
(4) mesoscale and small-scale eddy transport across the tropopause. (17:459)

It is assumed that fallout particles in the stratosphere are carried along with the air as it moves under the influences of the above processes. This should be true for the micron and submicron size particles that are injected into the stratosphere. These particles make up the world wide fallout burden. A short discussion of each of the above processes and how each can be applied to a world wide fallout model is included below.

Seasonal Tropopause Height Adjustments. This process is not a true process in that it does not directly cause the transport of air across the tropopause but rather is a result of the other processes. Figures 2a-d show the average change by latitude and season. Reiter (17:46)

points out that the primary causes of this change are processes 2 and 3. The stratospheric air mass can vary by as much as 10 percent from one season to another which causes a corresponding change in the tropopause height to accommodate the gain or loss of air mass (17:461). As is discussed below, processes 2 and 3 are used to model this air mass exchange.

Mean Meridional Circulation. The winds of the atmosphere have both vertical and horizontal components. J.F. Louis (19) has shown that it is possible to compute the mass flux of the atmospheric air masses based on the mean meridional and vertical wind velocities. These wind velocities are functions of height, latitude and season of the year. Their average values have been tabulated in tables (19:6-40 - 6-43). Louis derives the following equation to relate the vertical wind to the vertical mass flux (19:6-23 - 6-26):

$$\overline{w}\left(z,\phi\right) = \frac{-1}{\rho 2\pi r^2 \cos\phi} \frac{\alpha\Psi}{\alpha\phi} \tag{1}$$

where: $\overline{w}(z,\phi)$ = average vertical wind velocity
ϕ = latitude
r = radius of the earth
ρ = density of the air
Ψ = mass flux
z = altitude

By rearranging terms and integrating with respect to latitude, it is possible to compute the mass flux across the tropopause per latitude band. This is done in Appendix A. This calculation yields the mass flow, dm/dt per latitude band, from the air circulation at the given altitude and season of the year.

The results of Louis' work are shown in Figures 2a-d. The significance of this figure is that there are regular cells of circulation, called Hadley cells, that vary by latitude and season. It is the extensions of these cells into the stratosphere that cause increased or decreased mass flow by season and latitude. Note that the downward flow is greatest in the mid latitudes and that the cells penetrate the stratosphere the least during the summer. This agrees very well with the observed fallout patterns of larger amounts falling in the mid latitudes and a lessening of the fall during the summer months (13).

Large Scale Eddy Transports. For a technical description of the large scale eddy process see (17). A simple description of the process is that it is caused by the periodic movement of stratospheric air to the troposphere by the jet streams due to the variance of the height of the jet stream region and tropopause. Reiter has estimated the average annual amounts of air transported in this manner as about 405×10^{17} grams per year in the 40-60 degrees latitudes of the northern hemisphere and a total flow of 800×10^{17} grams per year over the whole northern hemisphere (17:467). It must be noted that these figures are averages, while the actual process tends to be more localized. The process was noted from studies of "occasional observations of relatively high concentrations of radioactive debris at ground level" (17:466).

Other Transports. Reiter discusses several other processes grouped under the title "Mesoscale and small-scale eddy transport across the tropopause" (17:469). These processes include thunderstorms that are large enough to penetrate the stratosphere, convective motions and other

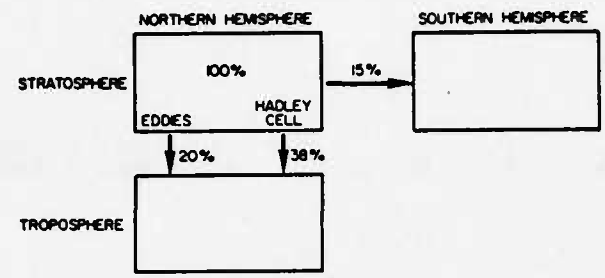

Figure 3. Annual Percent Mass Budget of Northern Hemisphere Stratosphere (15:470)

small eddy fluxes (17:469-472). He points out that either they are duplicated in other processes or are too small relative to other processes to be considered on a world wide basis. Thus they are ignored in the model. Note that these processes can be used as possible explanations for anomolously high local fallout patterns that vary from expected patterns.

Atmospheric Mass Exchange Budget. Reiter has calculated the average annual budget of air mass that is exchanged between the stratosphere and troposphere by taking into account the mass fluxes of processes 2 and 3 above. This has been done and is summarized in Figure 3. This shows that in the northern hemisphere about 58 percent of the air mass of the stratosphere is transferred to the troposphere annually. The 15 percent that is transferred within the stratosphere to the southern hemisphere supports the assumption that the fallout tends to stay in the hemisphere of injection. This transport across the equator is ignored in the model. As pointed out by Reiter the yearly transfer percentages tend

to support the idea that the mean residence time for fallout in the stratosphere is about 1.4 years (17:468). Thus the use of processes 2 and 3 to model the flow of air from the stratosphere to the troposphere as the mechanism to transport fallout particles appears to be justified.

Horizontal and Vertical Cloud Dispersion. When a nuclear device injects radioactive debris into the atmosphere the debris forms a cloud that travels outward from the injection point and disperses through the atmosphere with time. The normal procedure is to model the cloud as a gaussian distribution in 3 dimensions. However, in order it do so, it is necessary to compute the mean horizontal and vertical dispersions. Ernest Bauer has proposed a means of computing these dispersions based upon a tensor analysis of the atmosphere (19:6-39). The equations are:

$$\sigma_h^2 = 2\ Kyy\ t \tag{2}$$

$$\sigma_v^2 = 2\ Kzz\ t \tag{3}$$

where Kyy and Kzz are the mean eddy diffusion coefficients which are functions of height, latitude and season; and t is the time after the cloud has reached stabilization. These coefficients have been tabulated in (19:6-45 - 6-49). Using equations (2) and (3) it is possible to compute the vertical and horizontal growth of the gaussian cloud with time. It may be noted that the horizontal coefficients average 6 orders of magnitude greater than the vertical coefficients, translating into a 1000 fold greater horizontal growth versus vertical growth for the same time.

The following equations can be derived from the equations (2) and (3):

$$\sigma_h = \sqrt{2\ Kyy\ t} \tag{4}$$

$$\sigma_v = \sqrt{2\ Kzz\ t} \tag{5}$$

or

$$\sigma_h = Kkyy\ \sqrt{t} \tag{6}$$

$$\sigma_v = Kkzz\ \sqrt{t} \tag{7}$$

where Kkyy and Kkzz are the season, latitude, and height dependent coefficients of the time term. The variation of these coefficients can be seen in Figures 4 and 5. Note that the effect of the Hadley cells on dispersion can be noted in the large fluctuations of the coefficients as altitudes approach the tropopause (Figure 5).

Gravitational Fall

The other force that acts upon the fallout particles is the force of gravity. This force can be modeled simply in one of two ways. If the assumption is made that the particles are spheroids falling free in a viscous medium, Stokes law for free falling bodies can be used. This law can be denoted by the following:

$$6\pi N V_z r = \frac{4}{3}\pi r^3 \rho_f g \tag{8}$$

where N = dynamic viscosity
V_z = fall velocity
r = particle radius
ρ_f = particle density
g = gravitational constant (4:211)

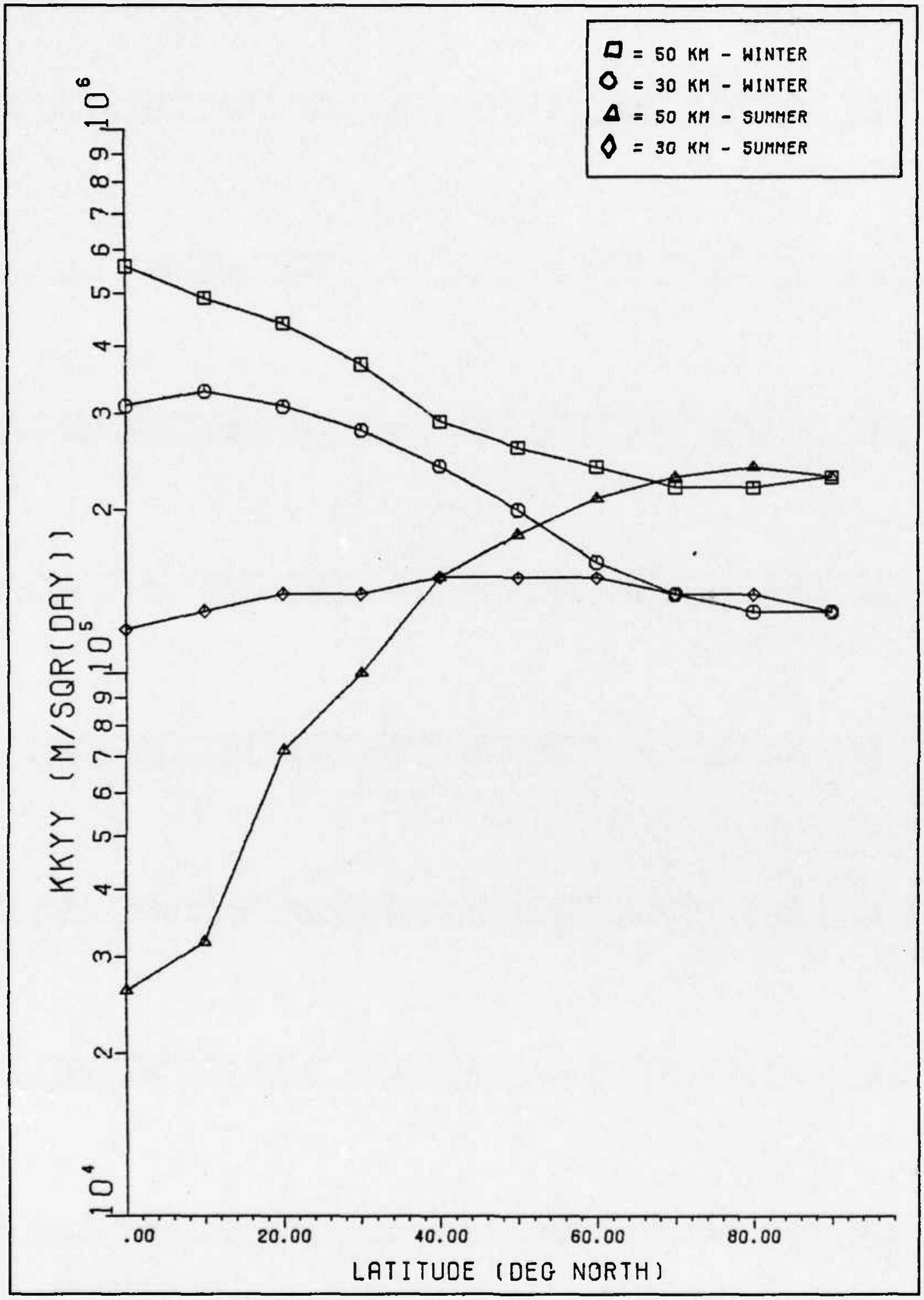

Figure 4. Horizontal Dispersion Coefficients For Various Seasons and Altitudes

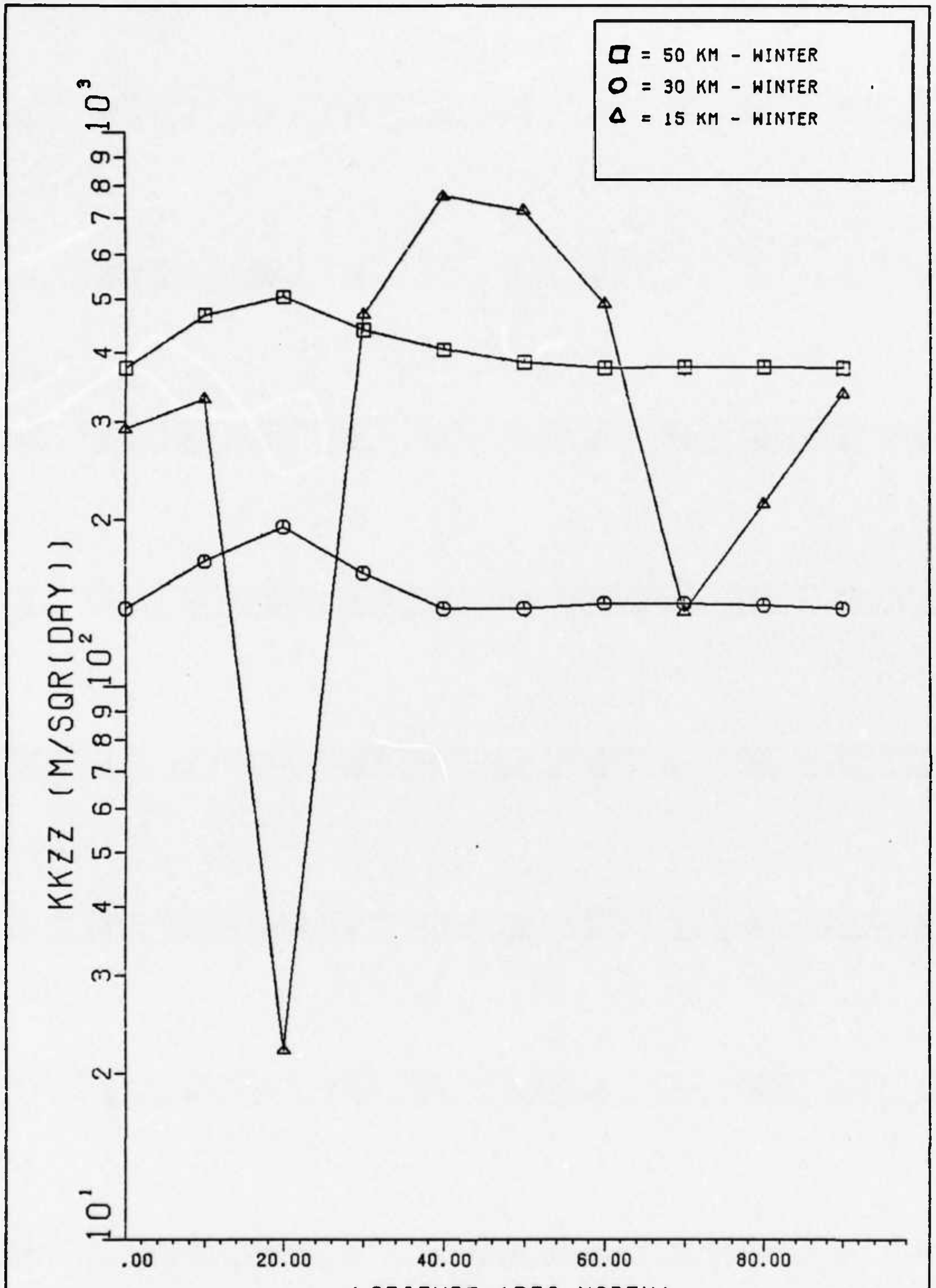

Figure 5. Vertical Dispersion Coefficients For Different Altitudes in the Winter Season

This law is not very good for particles greater than about 10 microns. For these particles, a better method is the one outlined by Bridgman and Bigelow in (6). This method accounts for aerodynamic drag by integrating into the calculations the Reynold's number of the particle. However, as will be seen, most of the particles associated with world wide fallout are less than 10 microns in size and Stokes law can be (and will be) applied.

Figure 6 shows the fall times for various size particles using Stokes law (derivation of fall-time equation in Appendix B). Note that the times become v ry large as the particle size gets smaller. If no other process was in effect, these would represent the times that the particles and their associated radioactivity would reach the ground. However, empirical data (15) show that the particles fall faster than this. Figure 7 shows the vertical velocity (at 12 km) versus particle size for various particles and also shows the average velocity due to the Hadley cells and large scale eddy transports (processes 2 and 3) discussed previously. The significance of this figure is that it shows that for larger particles Stokes law will dominate, while for smaller particles the air transport processes dominate. It is assumed that both velocities are vectors and therefore additive. Thus both gravitational fall and air mass transfer must be taken into account when modeling world wide fallout.

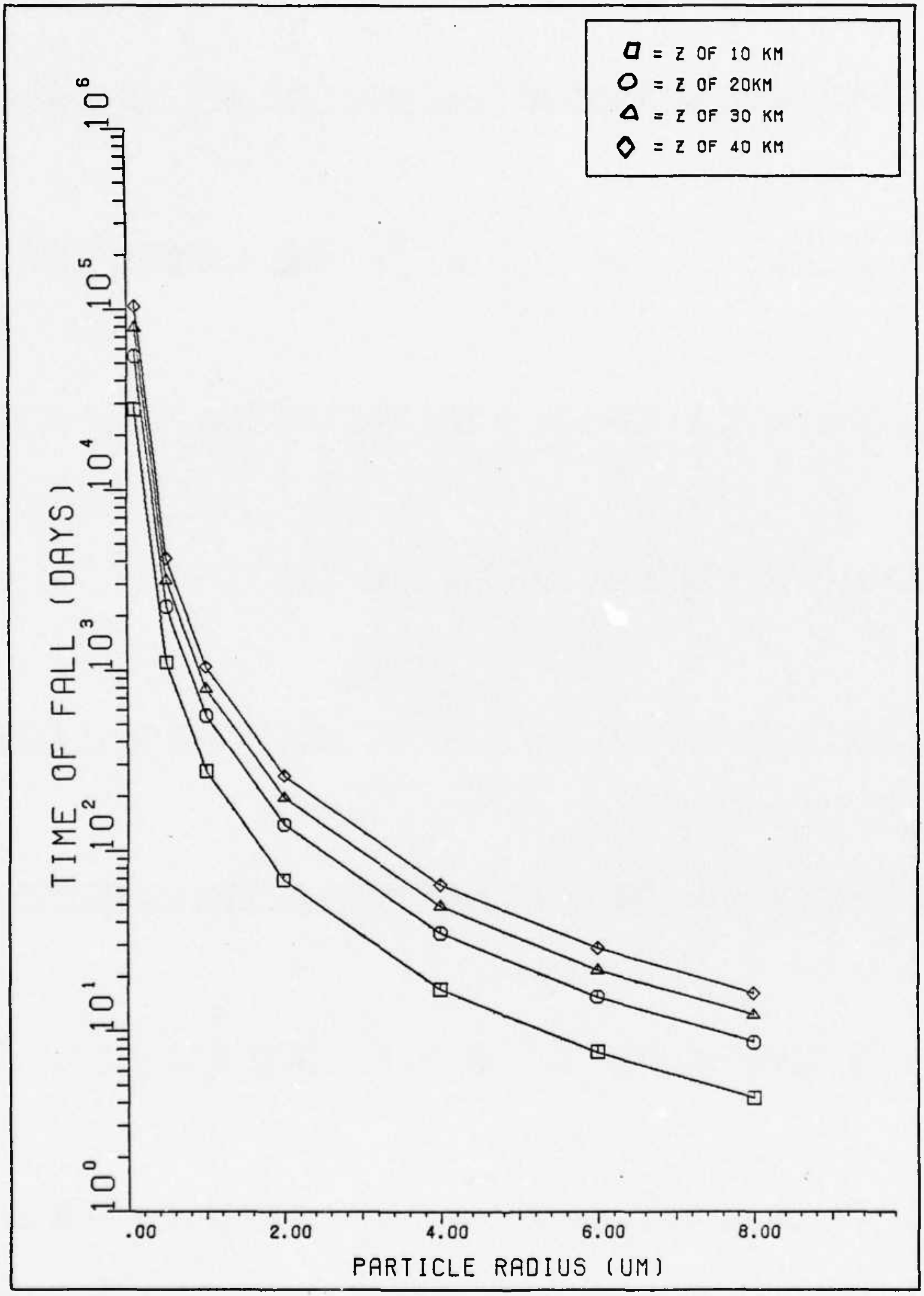

Figure 6. Stokes Law Fall Times From Z to Ground vs Particle Radius

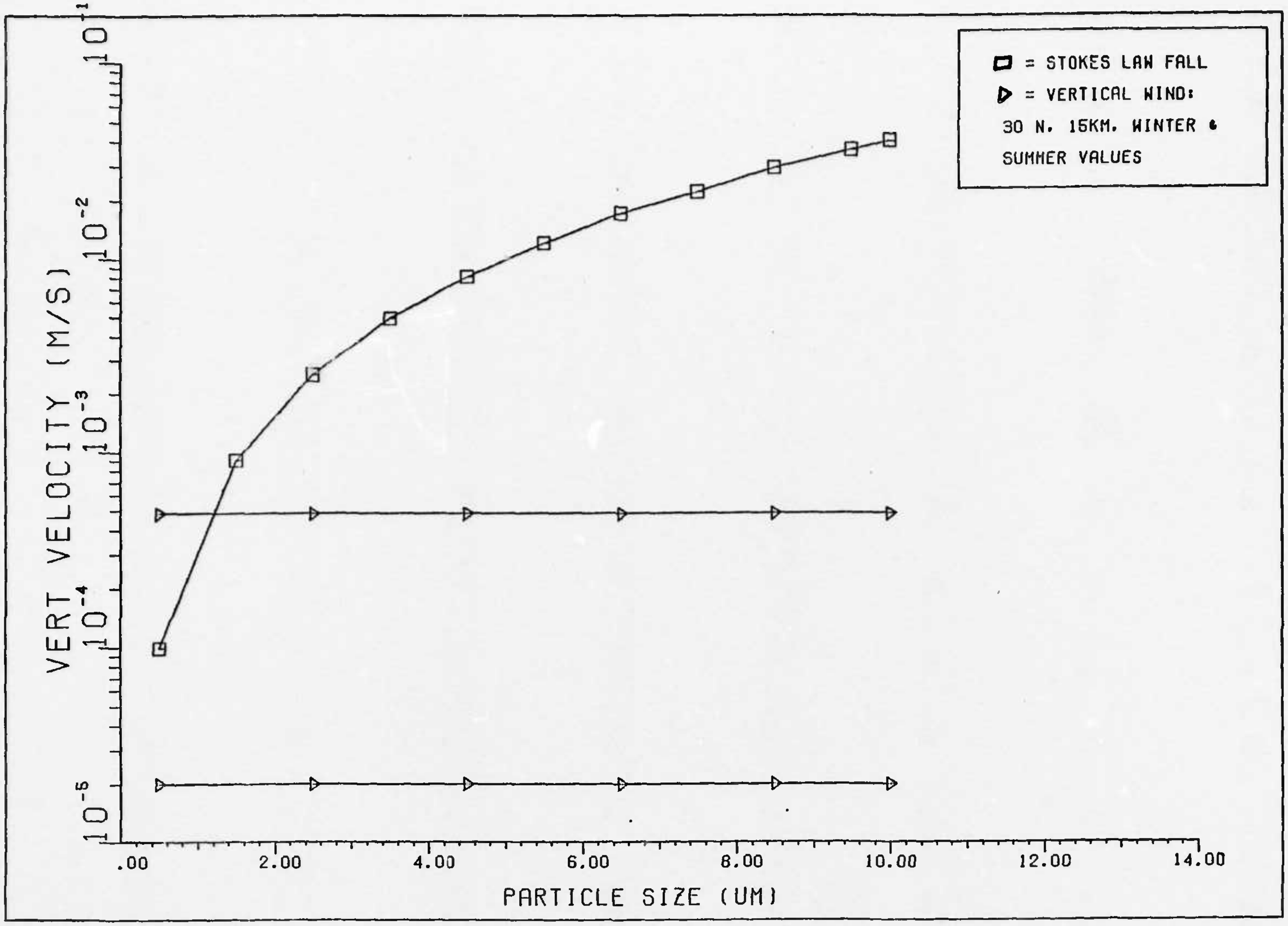

Figure 7. Stokes Law Vertical Velocity vs 2 Typical Vertical Wind Velocities For a Range of Particle Sizes

III. The Model

General

Appendix C provides the Logic Flow diagram of the computer program used to test the model. Appendix D is the code listing. In general, the model injects a stabilized nuclear cloud of activity at time $t = 0$ into the stratosphere. The cloud is allowed to grow in 3 dimensions with time after removing all activity that does not penetrate the stratosphere. As the bottom of the cloud reaches the tropopause the mass flow of air, with its associated activity, is allowed to transfer activity to the troposphere. This removal causes a new cloud bottom above the tropopause. The cloud continues to grow until it again reaches the tropopause and the cycle is repeated (see Figure 8). The model permits vertical motion of the cloud bottom across the tropopause but ignores vertical motion of the cloud top or cloud interior. It can be seen from Figure 2 that this is only approximately true. Vertical motion within the cloud is assumed to assist in the even distribution of the particles throughout the cloud volume.

The model as presented here assumes that once the activity is transferred to the troposphere it reaches the ground in a short time compared to the time span being considered for data analysis. Thus there is no calculation of tropospheric fall. How this can be integrated into the model using an exponential fall based on an average residence time is discussed below.

The remainder of this chapter discusses in detail the main points of the model and how the work of Bauer, Reiter, Lucas, et al. are integrated into the model.

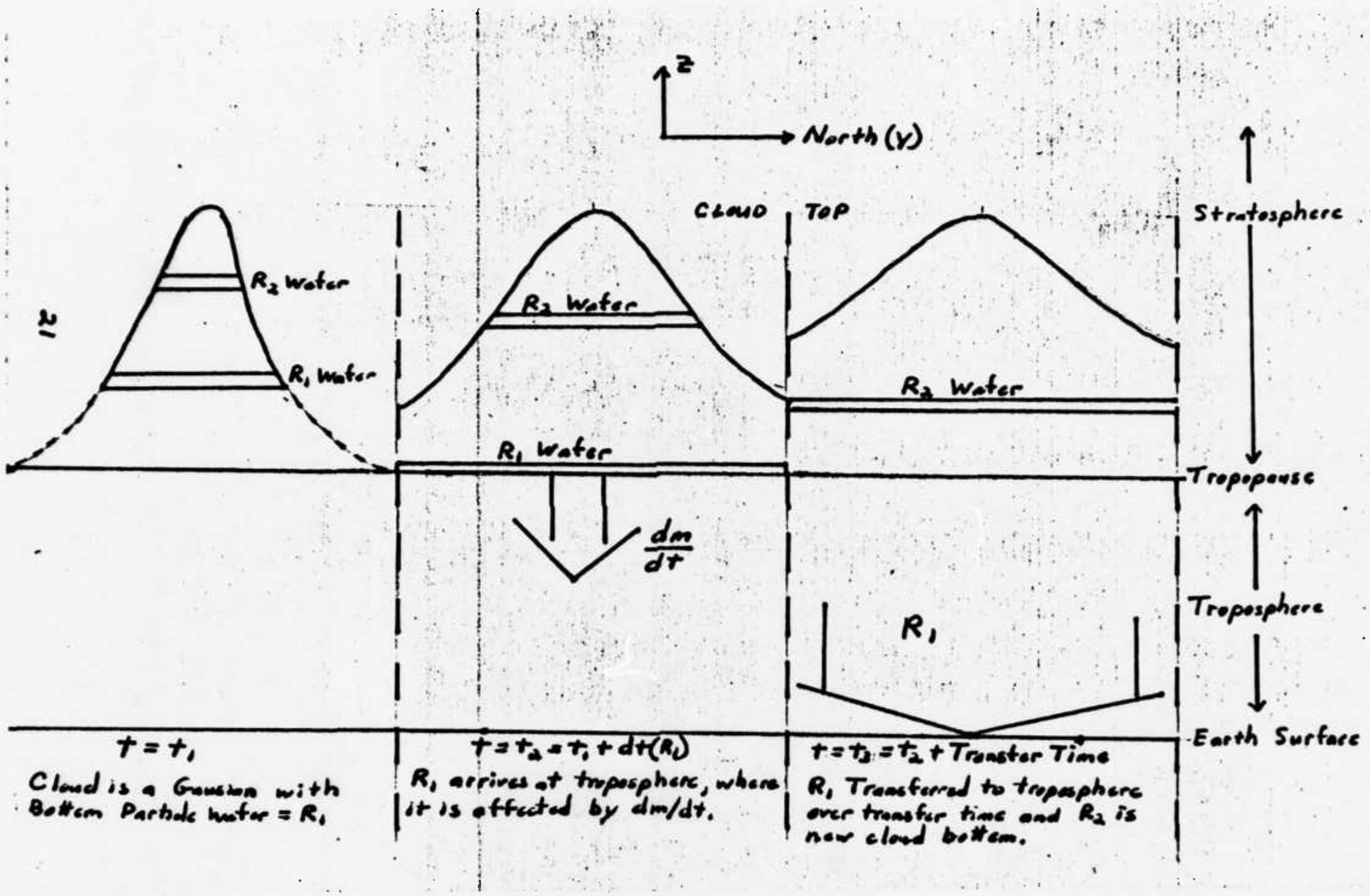

Figure 8. Conceptual View of Model

Use of a Tracer to Track Fallout Fall

Rather than tracking the total activity that a detonation would inject into the atmosphere, the radionuclide Strontium 90 (Sr90) is used as a tracer of the cloud. This is done for three reasons. First is that the 29 year half life (20:29) of Sr90 means that the decay of the nuclide can be ignored over the fallout period being considered. This simplifies the calculations.

The second reason for using Sr90 as a tracer is that empirical data available from the nuclear tests of the 50's and 60's is generally in terms of some tracer that the researchers could measure, such as strontium. As will be discussed below, the comparison data comes from the output of an empirical model that computes fall in kCi of Sr90 (15).

The third reason is that Sr90 has been called "the limiting factor of the extent to which human beings can tolerate global contamination by fission products" (10:364). This is due to its long life and the fact it is a bone-seeker (10:364).

It is assumed that each megaton of fission generates 0.1 megacurie of Sr90 (15:321). Note that this is the same yield that Peterson assumes in his empirical model (15:358).

If one is interested in total activity or the activity of another nuclide, it would be a relatively simple matter to change the yield equation and add in a decay term such as the commonly used Way-Wigner decay formula (12).

The Radioactive Cloud

The nuclear debris is injected into the atmosphere in the form of a cloud which is assumed to reach stabilization at time $t = 0$. At

stabilization the cloud is assumed to consist of a vertical distribution of particle sizes with the smaller particles being higher in the cloud. A log-normal distribution is used that is both surface and volume distributed. Activity is related to the particle sizes as (5):

$$A(r) = \frac{fv}{\sqrt{2\pi}\,\beta r}\, e^{-\frac{1}{2}\left(\frac{\ln r - \alpha_3}{\beta}\right)^2} + \frac{(1-fv)}{\sqrt{2\pi}\,\beta r}\, e^{-\frac{1}{2}\left(\frac{\ln r - \alpha_2}{\beta}\right)^2} \qquad (9)$$

where r = particle radius
rm = mean particle radius
σ = standard deviation of particle size distribution
fv = volume fraction
$\beta = \ln(\sigma)$
$\alpha_o = \ln(rm)$
$\alpha_3 = \alpha_o + 3\beta^2$
$\alpha_2 = \alpha_o + 2\beta^2$

The particular values assigned to the particle distributions are described on page 28.

The cloud is pictured as a series of wafers stacked upon each other with each wafer representing the region that most of the particles of a given radius are located. The higher the wafer, the smaller the particle radius. Each wafer is computed by assuming each particle radius is distributed in a gaussian distribution, and then defining a standard deviation from the gaussian peak as the region that most of the particles can be expected to be located in. This region is a wafer. Empirical Curve Fits to the data provide equations that give the wafer heights as a function of Weapon Yield.

The initial stabilized cloud top is calculated from an equation developed from an analysis of DELFIC values for various yields from 1 to 15 MT for various particle size wafers. The equation gives the "top" of each particle wafer. The assumption is made that the cloud top is the extrapolated zero particle radius wafer (Let Rp = 0 below). The equation is:

$$Ht = slope1\ (2\ Rp) + intercept1 \qquad (10)$$

where

Ht = average height of wafer top (m)
Rp = particle radius (um)

$$slope1 = -\exp\left[C_{01}+C_{11}\ln Y+C_{21}(\ln Y)^2+C_{31}(\ln Y)^3+C_{41}(\ln Y)^4\right] \qquad (11)$$

$$intercept1 = \exp\left[C_{02}+C_{12}\ln Y+C_{22}(\ln Y)^2+C_{32}(\ln Y)^3+C_{42}(\ln Y)^4\right] \qquad (12)$$

Y = weapon yield in kilotons
Cn = coefficients per Table 1 Equations from (8)

The initial bottom of the cloud is found in a similar manner using an equation developed to predict initial wafer centers. This equation is:

$$Hb = slope2\ (2\ Rp) + intercept\ 2 \qquad (13)$$

where

Hb = average height of wafer center (m)
Rp = Particle size (um)

$$slope2 = -\exp\left[C_{03}+C_{13}\ln Y+C_{23}(\ln Y)^2+C_{33}(\ln Y)^3+C_{43}(\ln Y)^4\right] \qquad (14)$$

$$intercept2 = \exp\left[C_{04}+C_{14}\ln Y+C_{24}(\ln Y)^2+C_{34}(\ln Y)^3+C_{44}(\ln Y)^4\right] \qquad (15)$$

Y = weapon yield in kilotons
Cn = Coefficients per Table 1 Equations from (14:14-15)

The coefficients for equations (11), (12), (14) and (15) are listed in Table 1.

Since the cloud bottom is a function of radius, the concept of a Radius Aloft (Ra) is introduced. Ra is defined as the largest size particle that is still in the stratosphere at time t, based on the amount

TABLE I

Coefficients of Wafer Height Equations (12:8;14)

Coefficient	n=1	n=2	n=3	n=4
C0n	1.61324	8.10667	1.574	7.889
C1n	-.0682128	.302301	-.01197	.34
C2n	.0843986	.0191831	-.03636	.001226
C3n	-.0123826	-.00748407	-.0041	-.005227
C4n	.000634405	.000518155	.0001965	.000417

of activity remaining in the cloud. The initial value of Ra is found by finding the Ra that has an initial wafer center height of 12 km using equation 13.

Cloud Growth

As the cloud grows it is assumed to be a gaussian in the Y - Z plane (see Figure 9) per the following equation:

$$fy = \frac{1}{\sqrt{2\pi}\,\sigma_y} \exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y} \right)^2 \right] \qquad (16)$$

where

σ_y = mean horizontal dispersion
y = horizontal distance

(see Figure 9). The value of the mean horizontal dispersion is a function of time and is found using the Bauer mean horizontal dispersion equation as discussed in Chapter II:

$$\sigma_y = \text{Kkyy sqr (t)} \qquad (17)$$

An average value of Kkyy is assumed of 200 km/day$^{1/2}$ (Figures 4 and 5).

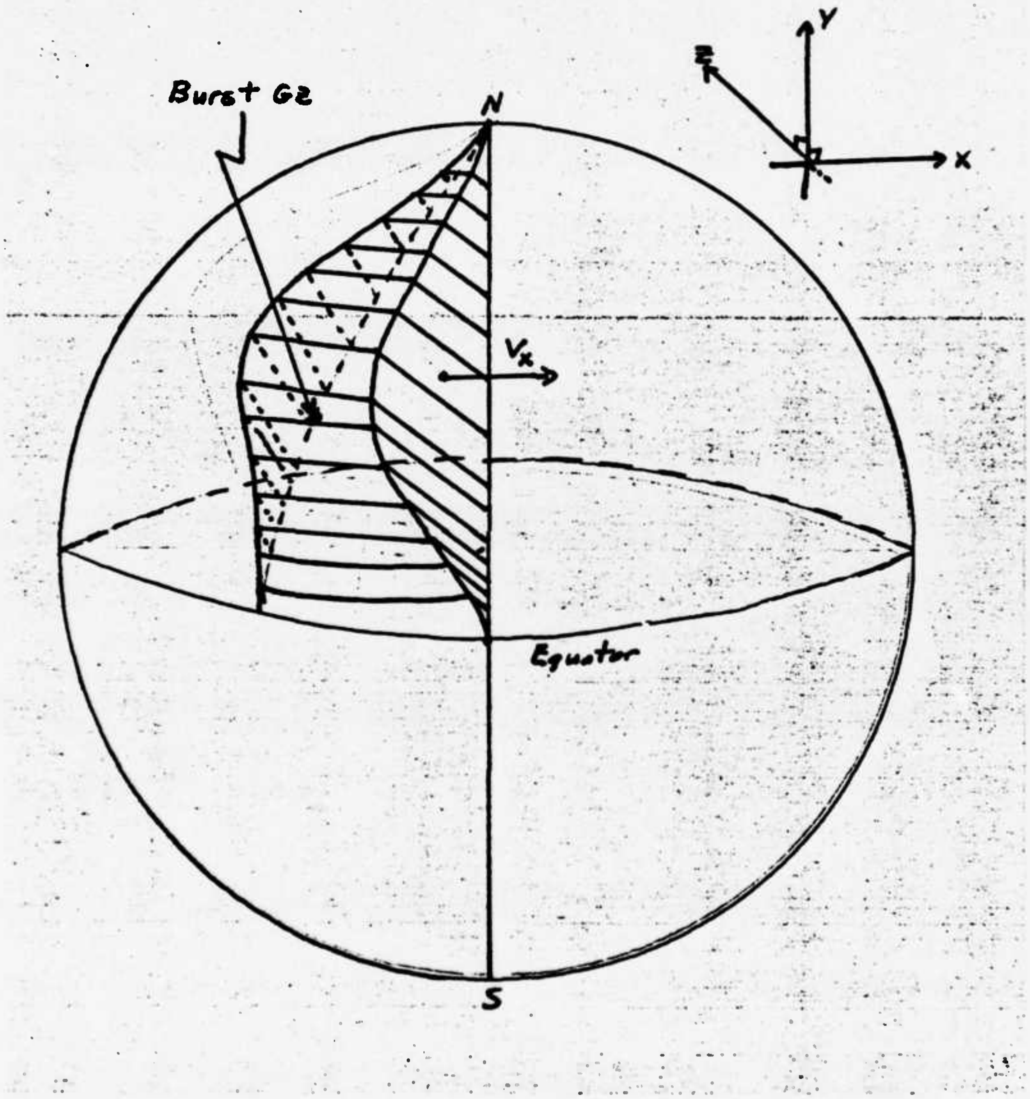

Figure 9. 3 Dimensional View of Activity Cloud

Note that the initial cloud radius is ignored. This is justified since values of less than 1 day are not important to the calculations and after 1 day any initial radius is small compared to a 3 sigma of 600 km. The gaussian is assumed to extend to the north pole and the equator where it is "chopped" off as if they act as walls (see Figure 8).

The cloud top is assumed to remain at a constant altitude. The reason for this is the 3 orders of magnitude difference between Kkyy and Kkzz as noted in Chapter II. It is assumed that cloud growth at the top is negligible after stabilization.

The cloud is assumed to grow in an easterly direction at a growth rate of 360 degrees of earth circumference per 16 days of cloud growth. This value is based on the observations of the average time required for tracers to circle the earth (5). Once the cloud has encircled the earth it is assumed to grow only in a north - south direction by increasing its height at the pole and equator.

Cloud Fall and Transfer to Troposphere

The cloud falls under the influence of two forces: the vertical wind and the force of gravity (Stokes law). The cloud bottom time of arrival (dt) at the tropopause is computed by finding the time it takes the current Ra to fall from its initial injection height to the tropopause. An average vertical wind is computed by numerically integrating the vertical wind tables (19:6-42 - 6-43) across the hemisphere and from the injection height to the tropopause. This dz/dt is added to the dz/dt calculated using Stokes law:

$$\left[\frac{dz}{dt}\right]_{\text{Stokes law}} = \frac{2}{9}\ \frac{Ra^2\ \rho_f g}{N} \qquad (18)$$

where

Ra = Radius Aloft
ρ_f = density of particles
g = gravitational constant
N = dynamic viscosity

The dt is found by dividing the distance to fall by the total dz/dt.

When the time for the cloud bottom to reach the tropopause has been calculated, the activity transferred across the tropopause is calculated using a mass flux of air, dm/dt. This dm/dt is the sum of two mass fluxes. First is mass flux found by integrating Lucas' equation (1) and using the vertical wind tables (see Appendix A). Second is the mass flux calculated by Reiter for large scale eddy currents (see Chapter II). Assumptions are made that the large scale eddies are actually localized events and would overcome any upward currents from the Hadley cells. Thus the upward Hadley cell air flow is ignored. This is justified since by including the upward Hadley cell air flow there would be latitude bands that would never receive fallout, due to some Hadley cell flow being greater than the average large scale eddy flow. The empirical data supports this assumption (15) since some fall is always seen even in the latitudes where the Hadley cell flow is upward. By assuming that the activity is evenly distributed throughout the cloud volume, the activity per mass of air can be calculated from the cloud volume and activity in the stratosphere at time t. Thus the amount of activity transferred to the troposphere can be determined once the amount of air

transferred is computed using the air mass flux. The transfer is accomplished using a variable time as each Ra reaches the tropopause. The activity transferred allows for a new calculation of the activity in the cloud and a new Ra. The assumption that the particles arrive at times based on particle size is implicit in the model.

Tropospheric Fall

The mean residence time for particles in the troposphere has been estimated to be about 30 days (11:446). Since in this study the time periods examined are seasonal and are on the order of 90 days it is assumed that once the particles are transferred to the troposphere they remain in their latitude bands and fall to the ground. By assuming that the fall is exponentially decreasing, the equation:

$$Fd = \exp\left[\frac{-(\ln 2)\,t}{t^{\frac{1}{2}}}\right] \tag{19}$$

where

Fd = fraction reaching the ground
t = time after transfer to troposphere
$t^{\frac{1}{2}}$ = mean residence time

can be used to calculate the fall for time periods of less than 90 days. However, this was not used in producing the results in Chapter V.

Particle Size Distributions

The particle number size distributions used in the study are listed in Table 2. The DELFIC default distribution is the default distribution used when using that computer model. It is based on Nevada soil and low

TABLE II

Particle Size Distributions

Distribution	Rm(um)	σ	Reference
DELFIC	.204	4	(5)
NRDL - N61	.00039	7.24	(6)

yield devices, and is a relatively large size distribution. The NRDL - N61 distribution is a relatively small distribution based on high yield weapons and Nevada soil.

These particle size distributions are converted to activity distributions using equation (9).

$$A(r) = \frac{fv}{\sqrt{2\pi}\,\beta r} e^{-\frac{1}{2}\left(\frac{\ln r-\alpha_3}{\beta}\right)^2} + \frac{(1-fv)}{\sqrt{2\pi}\,\beta r} e^{-\frac{1}{2}\left(\frac{\ln r-\alpha_2}{\beta}\right)^2} \tag{9}$$

where

r = particle radius
rm = mean particle radius
σ = standard deviation of particle size distribution
fv = volume fraction
$\beta = \ln(\sigma)$
$\alpha_o = \ln(rm)$
$\alpha_3 = \alpha_o + 3\beta^3$
$\alpha_2 = \alpha_o + 2\beta^2$

IV. Benchmark Data

General

The results of the model presented in this report are compared against an empirical model of world wide fallout developed by Kendall R. Peterson (15). This model uses the data obtained from the U.S. and U.S.S.R. tests of 1958 to develop tables that can be used to predict world wide fallout. Peterson's model predicts both surface and air burst fallout. For this study only the surface burst aspect of his model is used. The Peterson model is programed into a computer code which is included in Appendix F.

Strengths

The Peterson model does fairly well in its predictions of the 1961-1962 tests in the 10-70 degree latitude bands. The predicted values are within factors of 3 from the observed values when considering seasonal (90 day) fall (15:371). Agreement is even better when considering annual fall (15:374). The comparison of world wide annual fall (rather than by latitude bands) is very good between the empirical model and observed values.

Limitations

The main limitations of Peterson's model are that output is in 20 degree latitude bands and 90 day time periods. Also, each northern hemisphere surface burst is assumed to occur in one of 2 regions: either north of 30 degrees latitude or south of 30 degrees latitude.

This allows for a difficult decision on where to put the burst location and time when using this study's model for comparison runs. Burst locations of 15 degrees north and 50 degrees north are used for comparison of Peterson's model to the study's model.

V. Results and Discussion

General

The results of varying the burst yield, location and particle distribution are summarized in data sets in Appendix G. For this discussion the only parameter that will be varied will be the particle size distribution. The other parameters will be held constant to simplify the discussion. This is done since a review of the data indicates several trends that are common whichever parameters are used. The model that has been developed in this study is termed the report model. The empirical model developed by Peterson is referred to as the Peterson model or the empirical model. The data set selected for discussion assumes a 10 MT burst (surface), at 50 degrees north latitude, detonated on 15 April. This is compared to a 10 MT surface burst, in the polar region, detonated in the spring season under Peterson's empirical model (17). As noted in Chapter I, the report model assumes no fallout transport across the equator. The Peterson model does take this transport into account and the data is included in the data presented for discussion purposes.

The discussion makes comparisons of 3 factors between the report model developed here and Peterson's model: the fraction of activity remaining in the stratosphere versus time; the total fall from the stratosphere versus time; and the fall per latitude band versus season after burst. Also a comparison of the particle size distributions is made by comparing the Ra of each distribution versus time. Since Peterson does not provide a particle size distribution, no comparison can be made with the empirical model.

Fall By Latitude Bands

Table 3 summarizes the fall of activity (in kCi) by latitude band as predicted by the empirical model, and the report model using the two particle size distributions. Several points are evident by this data. First is the very high fallout in the season of the burst of the report model compared to the empirical model. The reason for this appears to be the particle size distributions used. Note that NRDL-N61 predicts fall that is about one half of DELFIC default. This is still ten times the empirical predictions, but leads to the possibility that a smaller (more small particles) distribution is present in the stratosphere than is predicted using DELFIC default or NRDL-N61. Since Stokes law is the effective force for transport across the tropopause for large particles, the circulation terms are being preempted by the gravity terms. This causes the large fallout at early times since in the two distributions relatively large fractions of activity are associated with relatively large particles.

The relationship between the values in season 2 is very constant except for the 30-10 degree band. This seems to indicate that the model is doing a reasonable effort of predicting the relative amounts of fall between latitude bands. This relationship continues with decreasing success with time. This is assumed to be due to the effect of the large initial fall, which means that the remaining activity is so low that there is not enough left to provide good results.

Another point to be made from Table 3 is that there is in fact much more transport of activity across the equator than expected. This can be attributed to the 15 percent of the stratospheric air that is

TABLE III

Comparison of Fallout by Latitude Band and Season
For 10 MT Burst, at 50 Degrees North, 15 April Detonation, ff = .4

Season after Burst	Distribution or Model*	Fallout Activity (KCi) per Latitude Band				
		Latitude Bands - Northern Hemisphere				
		90-70	70-50	50-30	30-10	10-0
Spring (Burst Season)	Peterson Model	.16	.33	.69	.19	0
	DELFIC Default	2.9	68.4	124.8	51.6	32.7
	NRDL-N61	1.09	35.4	63.0	9.6	15.0
Summer	Peterson Model	.02	.24	.92	.28	.01
	DELFIC Default	.6	.2	18.8	1.4	1.7
	NRDL-N61	.30	.11	6.1	.67	.51
Fall	Peterson Model	.08	1.04	2.07	.84	.15
	DELFIC Default	2.4	.1	25.5	9.1	.01
	NRDL-N61	.23	.01	3.08	6.26	.40
Winter	Peterson Model	.20	3.51	6.83	3.84	.16
	DELFIC Default	.1	.01	.5	4.3	.6
	NRDL-N61	.05	.01	.17	2.28	.32

*DELFIC Default and NRDL-N61 data are from the report model

transferred from the northern hemisphere to the southern annually. While this is not much in terms of the whole hemisphere, it is actually most of the air in the 0-20 latitude band, where it is reasonable to assume the air for the transport comes. Thus once the cloud grows enough to reach the equator, it will continue to expand in a horizontal direction. This effect will be more significant the closer the burst is to the equator since more of the cloud will arrive at the equator at an earlier time than for a burst farther away. This would explain the relatively large values of fall in the lower latitude bands. Some of this should be in the southern hemisphere.

Fraction of Activity in the Stratosphere

Figure 10 compares the fraction of activity in the stratosphere versus the time after cloud stabilization for the 2 models. This fraction of activity is computed by dividing the amount of activity in the stratosphere at time t by the total activity produced by the weapon. As with the discussion above, the report model predicts large amounts of early fall compared to the empirical model. The smaller distribution again provides a better comparison. Again it appears that a smaller distribution (either small σ or r_m) needs to be used to provide better results. The effect of the large very early fall makes it not possible to compare the rates of fall per season since the results are slanted by the early fall. However, the NRDL-N61 seems to indicate a trend that may continue with continually smaller distributions to match the empirical prediction.

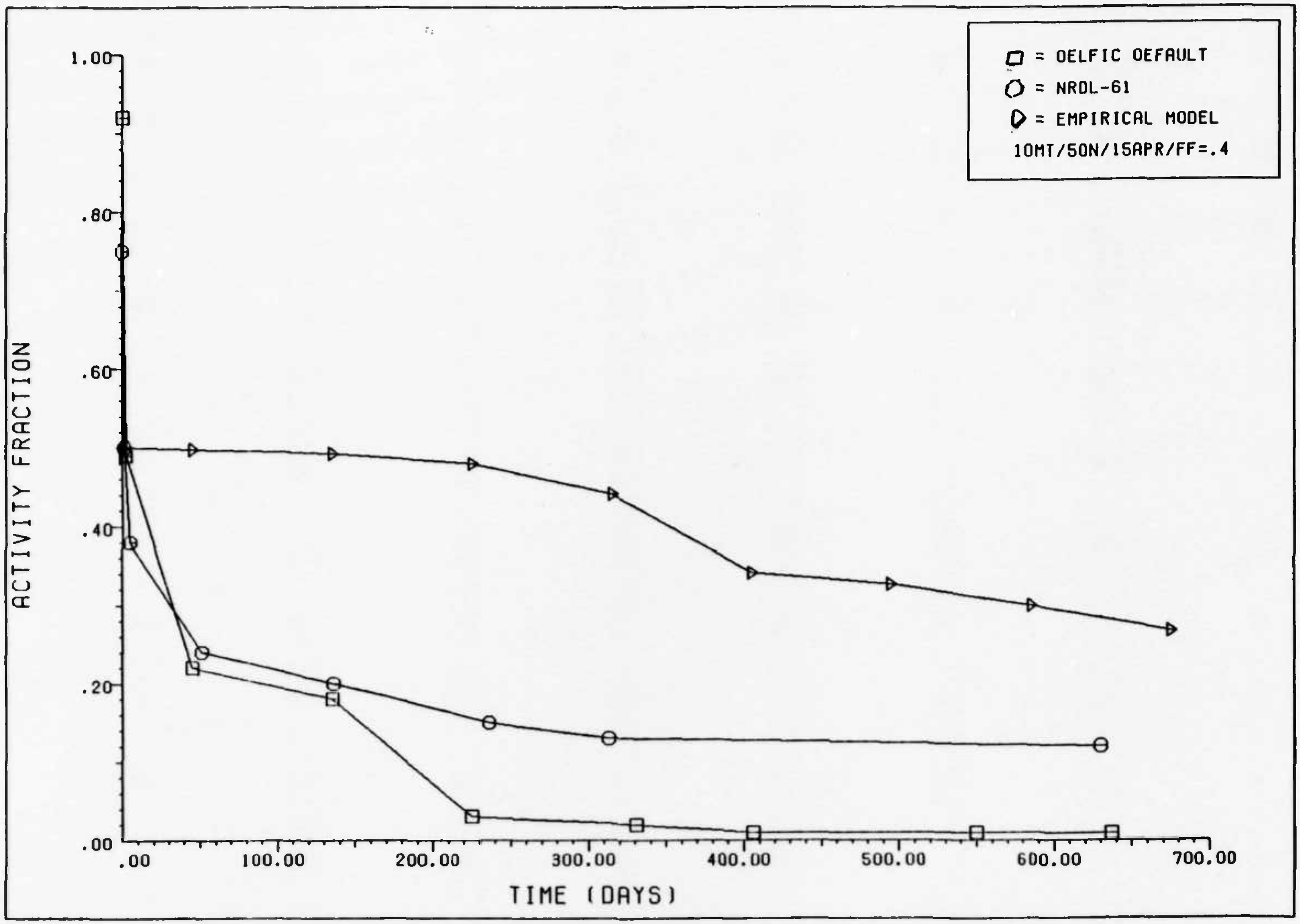

Figure 10. Comparison of Activity Fraction Remaining in the Stratosphere at Time t

Total Fallout to Ground

Figure 11 compares the total activity to fall versus the time after cloud stabilization for the two models. This graph again shows the effect of the particle distributions. Note that the fall predicted by the report model for days 0 to 2.1 are subtracted from the curves for DELFIC default and NRDL-N61. These values are 173. and 90.2 kCi respectively. The significance of this graph is that the slopes of the model again seem to be approaching the empirical prediction as the particle size distribution gets smaller.

Radius Aloft

Figure 12 compares the Radius Aloft (Ra) for the two distributions over time after cloud stabilization. The effect of the values of the NRDL-N61 distribution are clearly seen. When compared to Figure 11, the larger fraction of activity carried on smaller particles is demonstrated. This supports the idea that a model for world wide fallout needs a smaller particle distribution than either NRDL-N61 or DELFIC default.

Particle Size Distributions

Figure 13 allows comparison of the curves of the two particle size distributions: DELFIC default and NRDL-N61. Both of these distributions were based on observations and have been used for local fallout modeling successfully. The problem with using these is that the equipment used to measure particle sizes have problems measuring submicron particles. This means that the particle distributions may be slanted toward the

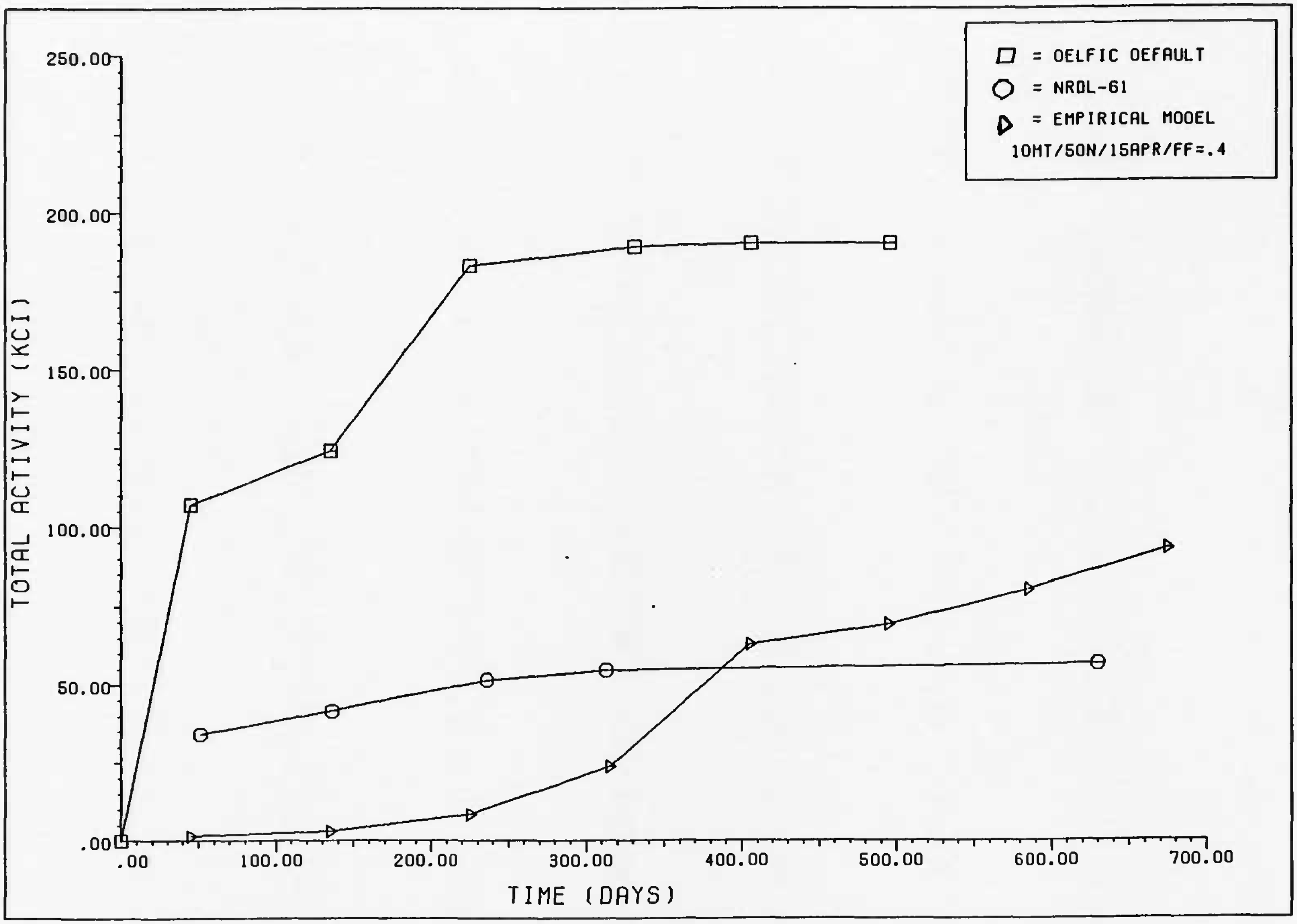

Figure 11. Comparison of the Total Activity to Reach the Ground at Time t
Activity in Troposphere at t = 0 not included

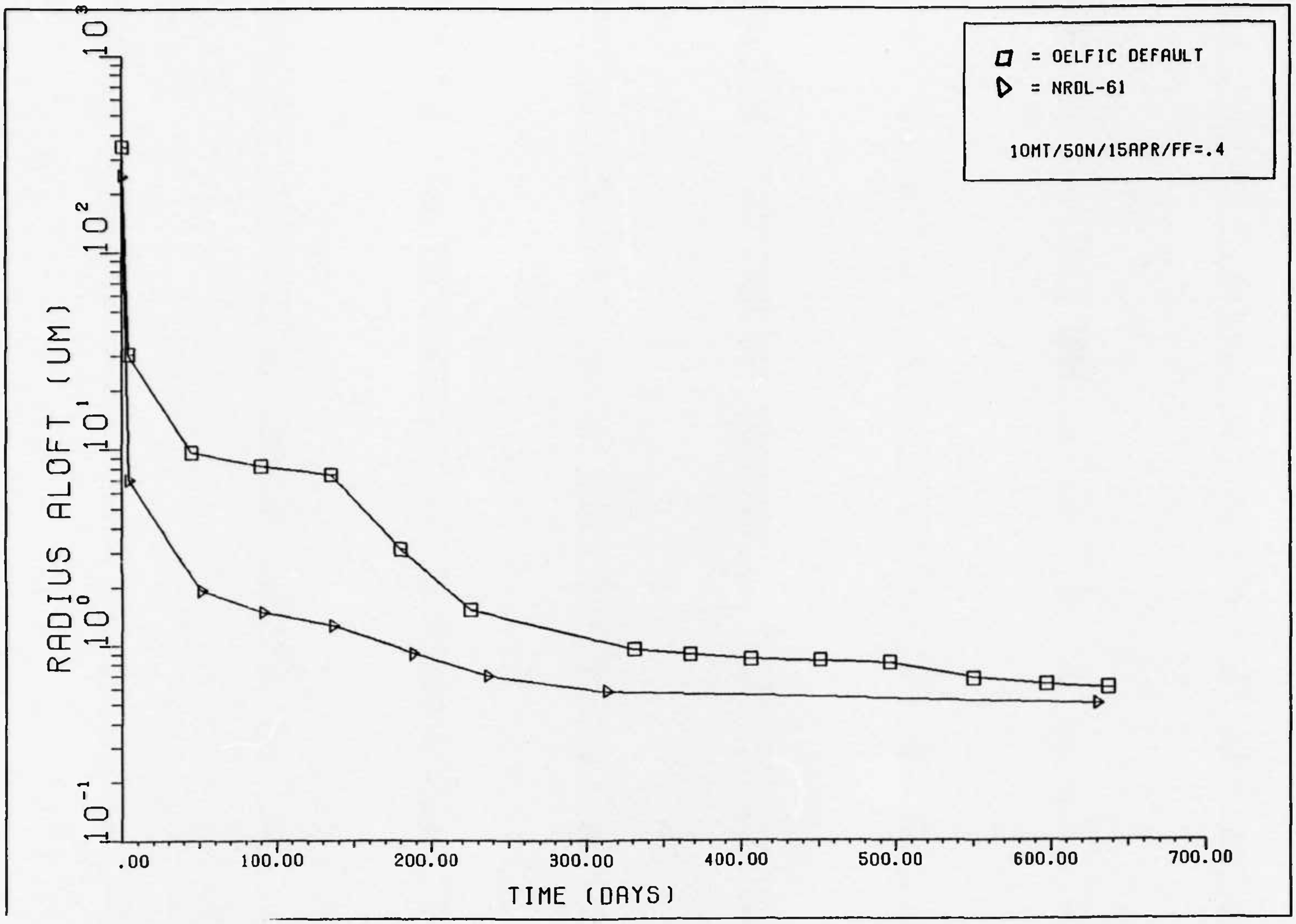

Figure 12. Comparison of Radius Aloft (Ra) at T

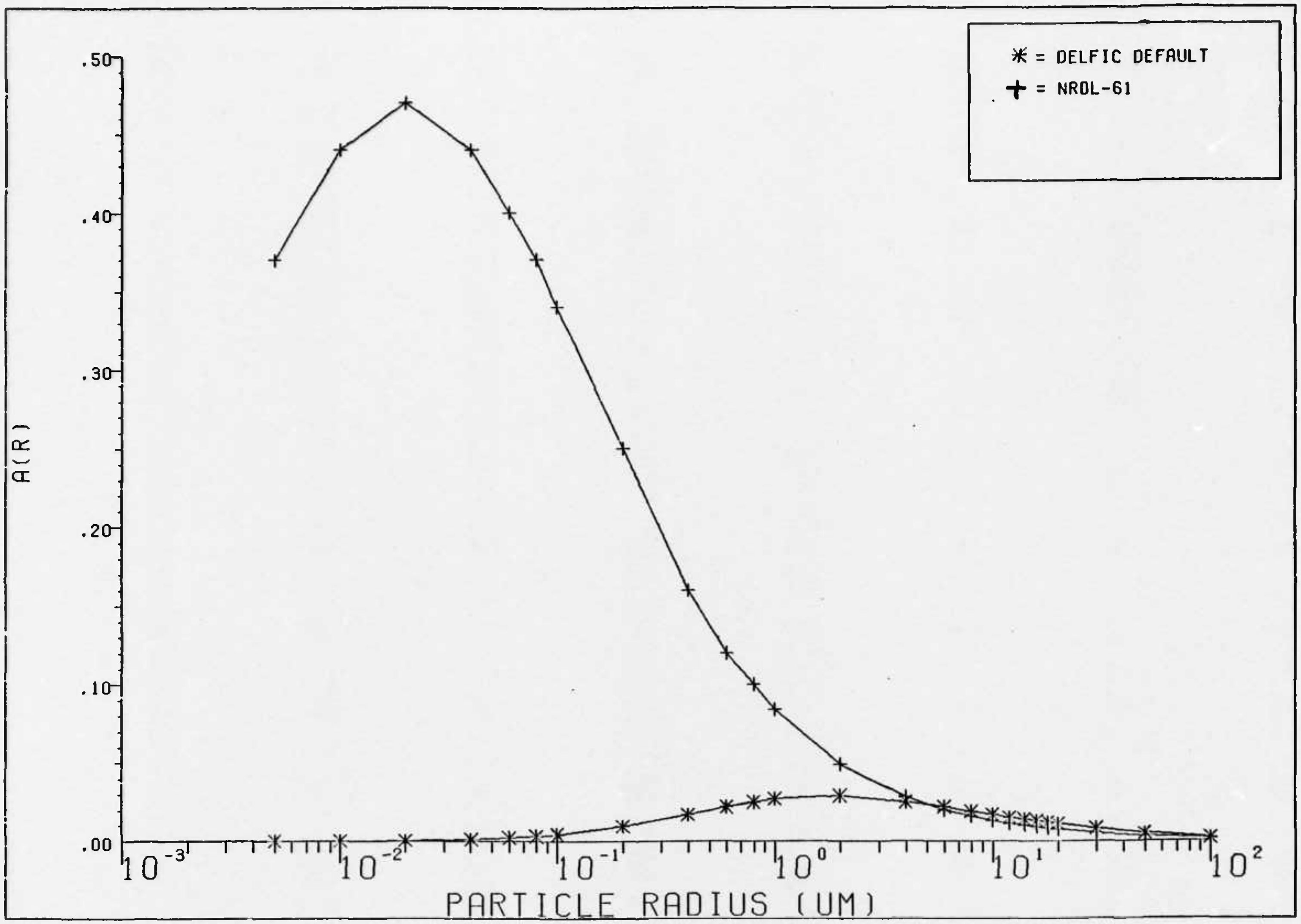

Figure 13. Comparison of Particle Size Distributions

larger particles. This is acceptable for local fallout predictions, which is made up of larger particles and is affected by mainly gravity and rainout. However for world wide fallout modeling which uses a fall-out distribution, better distributions are needed. It may be possible to view the particle distribution as the sum of two distributions. One, such as DELFIC default or NRDL-N61, which takes into account local fall-out, and another that is made up of small particles to account for world wide fallout. Basically the need is to increase the number of particles in the "tail" of the distribution. Such a distribution is schematically represented in Figure 14. Note that in this case the total distribution is actually "double humped."

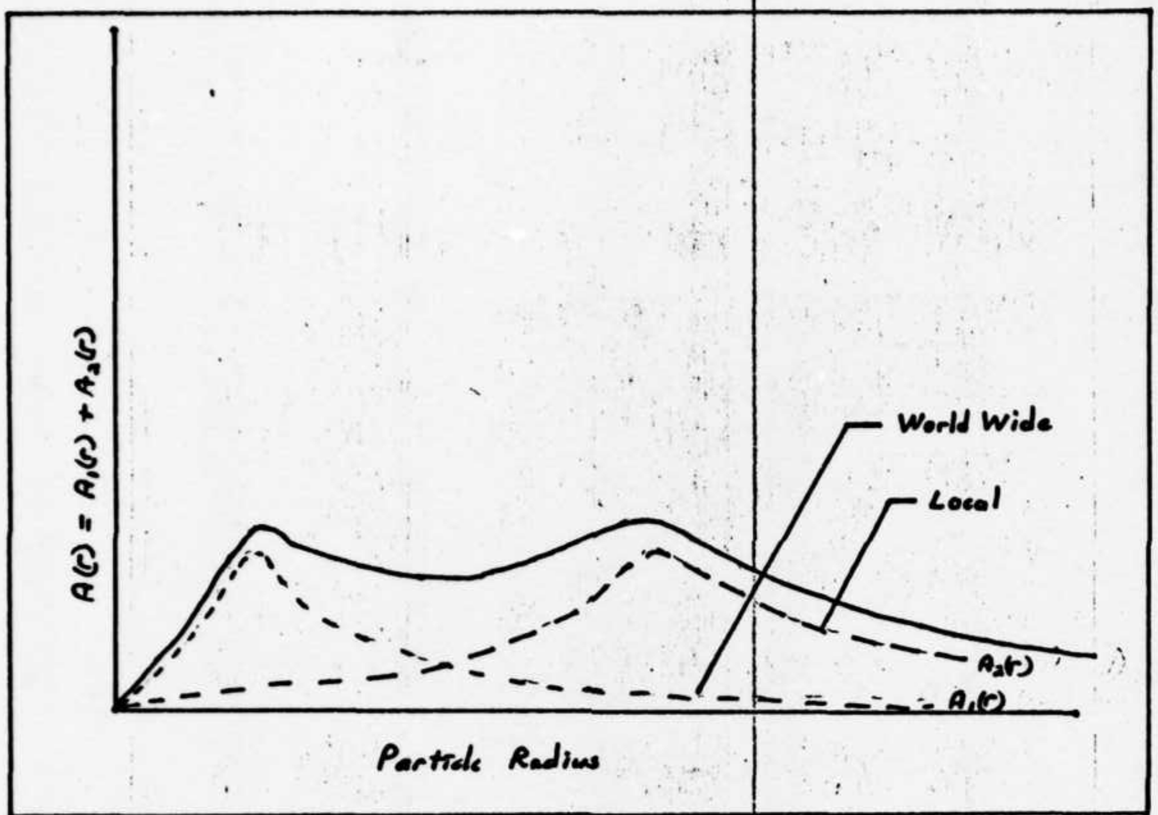

Figure 14. Conceptual Particle Size Distribution

VI. Conclusions and Recommendations

Conclusions

Based upon the results of the analysis of the model proposed to predict world wide fallout, the following conclusions are made:

1. The modeling of the stratosphere to tropospheric exchange processes is a viable method for predicting the return of fallout particles to the troposphere and subsequent arrival on the ground. The circulation of the air (Hadley cells and large scale eddies) account for the relative differences in fallout patterns observed for different seasons and latitudes.

2. The assumption that fallout is not transferred across the equator is not a good assumption. There appears to be a significant amount that travels to the other hemisphere. This must be accounted for when modeling world wide fallout.

3. The use of either the DELFIC default or NRDL-N61 particle size distributions in a volume/surface activity distribution is not justified for world wide fallout modeling. A better distribution is one that provides for more submicron size particles carrying more of the activity.

4. If an appropriate particle size distribution could be determined and the model extended to include (or account for) southern hemisphere fall, the model as presented in this report has good possibilities of being able to predict world wide fallout.

Recommendations

Based upon the results of this report, the following recommendations

are made for future study:

1. Develop a particle size distribution that accurately models the particle distribution of the fallout injected into the stratosphere.

2. Extend the model as presented in this report to include the southern hemisphere. In order to do this it may be necessary to use a larger computer than a personal computer since the program as listed in Appendix D takes about 3-4 hours to run out to a 2 year time cycle.

Appendix A: Derivation of the Airmass Flux Equation

From the work of Louis (15:6-26):

$$\bar{w} = \frac{-1}{\rho 2\pi r^2 \cos\phi} \frac{\alpha\Psi}{\alpha\phi} \qquad \text{(A-1)}$$

where

$\bar{w}$ = average vertical wind velocity - averaged over a season and latitude circle; function of altitude
ρ = density of air
r = radius of the earth
ϕ = latitude
Ψ = integrated mass flux

solving for $\alpha\Psi/\alpha\phi$

$$\frac{\alpha\Psi}{\alpha\phi} = -\bar{w}\rho 2\pi r^2 \cos\phi \qquad \text{(A-2)}$$

Change the partial derivatives to differentials and rearranging terms:

$$d\,\Psi = -\bar{w}\rho 2\pi r^2 \cos\phi d\phi \qquad \text{(A-3)}$$

integrating between latitude bands

$$\Psi = \int_{\phi_1}^{\phi_2} -\bar{w}\rho 2\pi r^2 \cos\phi d\phi \qquad \text{(A-4)}$$

Assuming that the air density and radius of the earth are not dependent on latitude:

$$\Psi = \rho 2\pi r \int_{\phi_1}^{\phi_2} \bar{w} \cos\phi d\phi \qquad \text{(A-5)}$$

The above equation can be solved numerically using the vertical wind tables that are tabulated in (15:6-42 - 6-43) to generate the mass flux per latitude band per season of the year, at a given altitude.

Appendix B: Stokes Law Time of Fall Derivation

Problem: Derive the time of fall of a particle of radius r from altitude Z_0 to altitude Z_1 using Stokes law (Z in meters).

Assumptions: Particle is a sphere falling in a viscous medium. No drag forces are present. From (14:14) Stokes law is:

$$6\pi N V_z r = \frac{4}{3} \pi r^3 \rho_f g \qquad \text{(B-1)}$$

where

$N = N(Z)$ = Dynamic Viscosity
ρ_f = density of particle
r = particle radius
g = acceleration due to gravity
v_z = vertical fall velocity

Solving for V_z: $V_z = \frac{2}{9} \frac{r^2 \rho_f g}{N}$

Let: $V_z = dz/dt$

Therefore: $dt = dz/V_z = \frac{9}{2} \frac{N}{r^2 \rho_f g} dz \qquad \text{(B-2)}$

Integrate from the particle height Z_0 to Z_1 and define this time as Ta:

$$\int_{z_0}^{z_1} dt = Ta = \int_{z_1}^{z_0} \frac{9}{2} \frac{N(Z)}{r^2 \rho_f g} \qquad \text{(B-3)}$$

Assume that r, ρ_f, and g are constants over Z_0 to Z_1 :

$$Ta = \frac{9}{2} \frac{1}{r^2 \rho_f g} \int_{z_0}^{z_1} N(Z)\, dz = k \int_{z_0}^{z_1} N(Z)\, dz \qquad \text{(B-4)}$$

Define the integral in equation (B-4) as Θ .

From U.S. Standard Atmosphere (16):

$$N(Z) = \frac{\beta \left[T(z)\right]^{3/2}}{T(z) + s} \qquad \text{(B-5)}$$

where:

$\beta = 1.458 \times 10^{-6}$ kg/sec-m- k
$S = 110.4\ ^{\circ}k$

And:

$$T(z) = \begin{cases} 288.15 - (.006545\ Z) & 0 <= Z <= 11000 \\ 216.65 & 11000 < Z <= 20000 \\ 216.65 + .001\ (Z-20000) & 20000 < Z <= 32000 \\ 228.65 + .0028\ (Z-32000) & 32000 < Z <= 47000 \end{cases} \qquad \text{(B-6)}$$

Consider two cases:

Case I: $11000 < Z <= 20000$

$$\Theta = \int_{z_0}^{z_1} N(z)\, dz = \int_{z_0}^{z_1} \frac{\beta\ (216.65)^{3/2}}{216.65 + s}\, dz \qquad \text{(B-7)}$$

$$= 1.42 \times 10\ (Z_0 - Z_1)$$

Case II: $11000 >= Z > 2000$

$$\Theta = \int_{z_0}^{z_1} N(z)\, dz = \int_{z_0}^{z_1} \frac{\beta \left[T(z)\right]^{3/2}}{T(z) + s}\, dz \qquad \text{(B-8)}$$

Differentiating equation (B-6):

$$dT(z) = \begin{cases} -.006545\ dz & 0 <= Z <= 11000 \\ .001\ dz & 20000 < Z <= 32000 \\ .0028\ dz & 32000 < Z <= 47000 \end{cases} \qquad \text{(B-9)}$$

or: $dT(z) = C\ dz$ (B-10)

Rewrite equation B-8 using the differential equations above:

$$\Theta = \frac{\beta}{C} \int_{z_0}^{z_1} \frac{\left[T(z)\right]^{3/2}}{T(z) + s} \, d\,T(z) \tag{B-11}$$

From (8:49):

$$\int \frac{x^{3/2}\,dx}{a^2 + b^2 x} = \frac{2}{3} \quad \frac{x^{3/2}}{b^2} - \frac{2a^2\,x^{1/2}}{b^4} + \frac{2a^2}{b^5}$$

$$\tan^{-1}\left(\frac{bx^{1/2}}{9}\right) \tag{B-12}$$

Let x = T(z), b = 1, a = sqr(s). Therefore:

$$\Theta = \frac{\beta}{C} \left[\frac{2}{3} T(z)^{3/2} - 2\;s\;T(z)^{1/2} + 2\;s\;\tan^{-1} \frac{T(z)^{1/2}}{\sqrt{5}} \right|_{z_1}^{z_0} \tag{B-13}$$

or: $\Theta = (\beta/C) \quad [\,F(Z_0) - F(Z_1)]$ (B-14)

where:

$$F(z) = \frac{2}{3} T(z)^{3/2} - 2\;s\;T(z)^{1/2} + 2\;s\;\tan^{-1}\left(\frac{T(z)}{s}\right) \tag{B-15}$$

In order to calculate Θ, the distance $Z_0 - Z_1$ must be broken up into regions where T(z) changes functions; and Θ is the sum of the Θ ; from each region. For example: if Z_0 = 40000 m and Z_1 = 0 m:

$$\Theta\;(40000 \text{ to } 0) = \frac{\beta}{C} \left[F(11{,}000) - F(0)\right] + 1.42 \times 10^{-5} \left[20{,}000 - 11{,}000\right]$$

$$+ \frac{\beta}{C} \left[F(32000) - F(20000)\right] + \frac{\beta}{C} \left[40{,}000 - 32{,}000\right]$$

The time of fall is simply: $Ta = K \quad \Theta$ (B-16)

Appendix C: Computer Program Logic Flow

1. Define constants and dimension arrays

2. Enter burst initial conditions:
    a. Burst latitude
    b. Weapon yield and fission fraction
    c. Date of burst

3. Convert input data into form for computations

4. Read into memory vertical wind data tables and calculate the mass flux (dm/dt), of air, from the Hadley cell circulation per 1 degree latitude bands

5. Calculate the mass flux (dm/dt) from large scale eddies

6. Calculate the average air density of the cloud and find the total mass flux, of air, across the tropopause per 1 degree latitude bands

7. Input into memory the average vertical wind tables

8. Calculate the initial stabilized cloud parameters:
    a. Let t = 0 as time that cloud reaches stabilization
    b. Calculate cloud top.
    c. Calculate Ra as particle size with wafer center at tropopause
    d. Calculate fraction of total activity in stratosphere
    e. Calculate total activity and activity in stratosphere

9. Calculate the delay time (dt) that accounts for the fall time of particle size Ra to reach the tropopause

10. Let t = t + dt + a time to allow for transfer of air across the tropopause (ft)

11. Calculate cloud parameter at time = t
    a. The mean horizontal (Y) dispersion
    b. The distance the cloud travels around the earth (X)
    c. Total cloud volume and volumes of 1 degree latitude sections
    d. Calculate the activity per volume ratio of the cloud and the activity per 1 degree latitude section

12. Calculate the activity per mass of air ratio of each 1 degree latitude section

13. Calculate the cloud transport across the tropopause
    a. Calculate the activity transferred per 1 degree latitude band

b. Add the 1 degree values into 10 and 20 degree bands of latitude
c. Update the stratospheric activity burden by subtracting activity transferred to troposphere

14. Calculate the new cloud bottom Ra from the activity still in the stratosphere

15. Print the output:
    a. Current time after burst
    b. Current season
    c. Ra and fraction of total activity in stratosphere, at t.
    d. Activity still in stratosphere
    e. Current and total fall in t for latitude bands -
       0 - 10 degrees
       10 - 30 degrees
       30 - 50 degrees
       50 - 70 degrees
       70 - 90 degrees

16. Go to step 9 to go to next time step

Appendix D: Computer Code Listings for the Report Model

The computer code listing of the program used to test the report fallout model is included in the following pages. The program shown is for the DELFIC default particle size distribution. In order to run another distribution appropriate changes must be made in the code. The program is GW - BASIC, version 1.0. It was programed into a Zenith Z-150 series computer.

This appendix also includes the programs used to generate the data files needed to run the program (VWLAT.DAT and VWIND.DAT). The vertical wind tables are from (17:6-42 - 6-43).

```
1 LPRINT"This code uses the DELFIC default"
2 lprint"particle size distribution"
10 REM *****************************************************
20 REM WORLD WIDE FALLOUT MODEL 3 - NORTHERN HEMISPHERE - Sr 90
30 REM -----------------------------------------------------
40 REM The model uses mass flux across tropopause to predict
41 REM world wide fallout from particles injected into the
42 REM stratosphere.  The mass flux takes into account Hadley
43 REM cell activity, large scale eddies and gravitational fall
44 REM (Stokes law).  Calculations are done in 1 deg lat bands
45 REM and variable time steps.  Output is in in 20 degree lat-
46 REM itude bands.
120 REM ____________________________________________________
130 REM Define constants and define arrays
140 GOSUB 1000
150 REM ____________________________________________________
160 REM Request input of burst data
170 GOSUB 1200
180 REM ____________________________________________________
190 REM Convert input data to form for computations
200 GOSUB 1500
205 LET DAYO = DAY
210 REM ____________________________________________________
220 REM Calculate and input into memory mass flow data for
225 REM cells and large scale eddies and calculate total dmdt
226 REM at tropopause
230 GOSUB 2000
235 GOSUB 3500
236 GOSUB 5500
240 REM Input into memory average vertical winds
242 GOSUB 2500
245 REM ____________________________________________________
250 REM Calculate the initial stratospheric injection and the
260 REM initial Ra (largest particle aloft)
265 GOSUB 5000
266 LET T = 0
267 LET COUNT = 0
271 REM_____________________________________________________
272 REM Calculate delay (dt) due to fall of Ra from injection
273 REM height to tropopause
274 IF T=0 THEN 275 ELSE 276
275 LET DT = 0: LET FT = .1: GOTO 295
276 GOSUB 4000
280 REM ____________________________________________________
290 REM advance time by dt and a fall time (ft)
292 LET FT = DT: IF FT>1 THEN LET FT = 1
293 IF DT=0 THEN LET FT = 1
295 LET T = T+FT+DT: LET DAY = DAY+FT+DT
296 IF DAY>365 THEN LET DAY = DAY-365
300 PRINT "time = "T,"dt = "DT
```

```
305 GOSUB 1800
310 REM_____________________________________________
360 REM calculate sigma-y, 'X' distance traveled, cloud
365 REM volume, activity per volume, and activity per lat band
371 GOSUB 6000
372 PRINT"sigma y = "SIGY,"X = "X" deg": PRINT
375 REM ____________________________________________
380 REM calculate the activity/mass of air ratio per lat band
390 GOSUB 7000
400 REM ____________________________________________
410 REM Calculate the mass of air removed per lat band,amount
420 REM of activity, and the new stratospheric burden and the
421 REM new Ra
430 GOSUB 7500
436 PRINT"time = "T,"Ra = "RA,"fract = "FRACT
440 REM ____________________________________________
480 REM Go to next day or print output or end program
482 LET COUNT = COUNT+FT+DT
483 IF COUNT>=45 THEN 490 ELSE 495
490 GOSUB 9000: LET COUNT = COUNT-45
495 IF T >= TF THEN 500 ELSE 496
496 IF T<5 THEN GOSUB 9000
497 GOTO 271
500 END
1000 REM --------------------------------------------------
1010 REM Subroutine: to define constants and arrays
1015 REM --------------------------------------------------
1020 LET PI = 3.1416
1022 LET RHOF = 2600
1030 DIM W(4,90),TDATA(4,50,9),VWLAT(4,50,9),AVWHZ(4,50),AV(4)
1031 DIM DMDTH(4,89),Y(100),DMDTE(89),DMDT(4,89),FALL(89)
1032 DIM LFALL(5),TFALL(5),F(2),MDAYS(12),AVOL(89)
1035 DIM ACT(89),VOL(89),ACTMASS(89),FZ(2),AREA(89),M$(12)
1050 LET COUNTER = 0
1060 FOR I=1 TO 5: LET TFALL(I) = 0: NEXT I
1190 RETURN
1195 REM
1200 REM --------------------------------------------------
1210 REM Subroutine: to input initial burst data
1220 REM --------------------------------------------------
1225 LET TF = 720
1230 LET BLAT = 20
1240 LET YKT = 5000!: LET FF = .4
1250 LET BMONTH$ = "APRIL": LET BDAY = 15
1300 LPRINT"For Burst at lat = "BLAT "N"
1310 LPRINT"Yield = "YKT" Ykt : Fission Fraction = "FF
1320 LPRINT"Date of Detonation = "BMONTH$" "BDAY:LPRINT
1400 RETURN
1500 REM --------------------------------------------------
1510 REM SUBROUTINE: to change burst data to usable forms
```

```
1525 REM for the code.
1520 REM -----------------------------------------------------
1530 REM
1540 REM change burst date to julian date
1550 DATA JANUARY,31,FEBRUARY,28,MARCH,31,APRIL,30,MAY,31
1560 DATA JUNE,30,JULY,31,AUGUST,31,SEPTEMBER,30,OCTOBER,31
1561 DATA NOVEMBER,31,DECEMBER,31
1570 FOR I=1 TO 12
1580   REEAD M$(I),MDAYS(I)
1590  NEXT I
1600 LET DAY = 0
1610 FOR I=1 TO 12
1620   IF BMONTH$=M$(I) THEN GOTO 1650
1630   DAY = DAY+MDAYS(I)
1640  NEXT I
1650 LET DAY = DAY+BDAY
1660 REM determine the latitude band of the burst
1670 LET BLBAND = 1
1680 FOR L=90 TO 0 STEP -10
1690   IF BLAT == 90 THEN GOTO 1710
1700   IF BLAT<L AND BLAT>=L-10 THEN  GOTO 1800
1710   BLBAND = BLBAND+1
 1720  NEXT L
1800 REM calculate the season of the burst
1810 IF DAY <= 59 OR DAY>=334 THEN LET SEASON = 1
1820 IF DAY>59 AND DAY<=151  THEN SEASON = 2
1830 IF DAY>151 AAND DAY<=243 THEN SEASON = 3
1840 IF DAY>243 AND DAY <334 THEN SEASON = 4
1850 RETURN
2000 REM -----------------------------------------------------
2010 REM Subroutine to calculate Hadley cell dm/dt for
2020 REM 1 deeg lat bands per season for input burst data
2030 REM -----------------------------------------------------
2040 REM
2080 LET RE = 6371315!
2090 LET HTKM = 12: LET HTM = 12000!
2100 REM read wind data into memory
2105 OPEN"I",#1,"VWIND.DAT"
2106    FOR S=1 TO 4
2107      FOR L=0 TO 50 STEP 5
210 8        FOR LAT=0 TO 9
2109          INPUT#1,TDATA(S,L,LAT)
2110         NEXT LAT
2111       NEXT L
2112     NEXT S
2113   CLOSE#1
2130 LET HTBURST = HTKM
2140 REM calculate density of air at the tropapause height
2150 LET H = HTM
2160 GOSUB 9500
```

```
2170 REM calculate the vertical winds using linear interpolation
2180 GOSUB 2930
2190 REM compute dm/dt usiing trapezoidal integration
2200 GOSUB 3130
2210 RETURN
2500 REM -----------------------------------------------
2510 REM SUBROUTINE: To input into memory the average vertical
2520 RREM winds and to compute the average vertical wind per
2522  REM height and season.
2530 REM -----------------------------------------------
2550 OPEN"I",#2,"vwlat.dat"
2560   FOR S=1 TO 4
2570     FOR HZ = 0 TO 50
2580       FOR LAT = 0 TO 9
2590       INPUT#2,VWLAT(S,HZ,LAT)
2600      NEXT LAT
2610    NEXT HZ
2620 NEXT S
2630 CLOSE #2
2640 FOR S=1 TO 4
2650   FOR HZ = 0 TO 50
2660     LET SUM = 0
2670     FOR LAT = 1 TO 8
2680       LET SUM = SUM+2*VWLAT(S,HZ,LAT)
2690      NEXT LAT
2700     LET AVWHZ(S,HZ)=(.5*(VWLAT(S,HZ,1)+SUM+VWLAT(S,HZ,9))/9
)*.001*3600*24
2710    NEXT HZ
2720  NEXT S
2730 RETURN
2930  REM -----------------------------------------------
2940 REM SUBROUTINE: to interpolate the vertical wind tables
2950 REM to determine a vertical wind at each 10 deg latitude
2951 REM increment at trop height.
2960 REM -----------------------------------------------
2970 REM
2975 REM calculate 12 km data
2976 FOR S=1 TO 4
2977   FOR LAT=0 TO 9
 2980      LET TDATA(S,12,LAT) = (TDATA(S,15,LAT)-TDATA(S,10,LAT))
*(2/5)+TDATA(S,10,LAT)
2981     NEXT LAT
2982  NEXT S
 2990 REM interpolate to 1 deg increments
3000 FOR S=1 TO 4
3005   LET LAT = 0
3010   LET W(S,0) = TDATA(S,12,0)
3015     FOR L=0 TO 8
3020       FOR I=1 TO 10
3030         LET LAT = LAT+1
```

```
3035         LET W(S,LAT) = (TDATA(S,12,L+1)-TDATA(S,12,L))*(I/1
0)+TDATA(S,12,L)
3040         NEXT I
3045       NEXT L
3050 NEXT S
3120 RETURN
3130 REM -----------------------------------------------------
3140 REM SUBROUTINE: to calculate mass flux per latitude band
3145 REM from Hadley cells.
3150 REM -----------------------------------------------------
3160 REM
3170 FOR I=1 TO 4
3180   LET LAT = -1
3190   FOR J=1 TO 90
3200     LET LAT = LAT+1
3210     LET HN = .1
3215     LET YA = W(I,LAT)*COS(LAT*PI/180)
3220     IF LAT=89 THEN 3230 ELSE 3260
3230       LET YB = 0
3240       GOTO 3270
3260     LET YB = W(I,LAT+1)*COS((LAT+1)*PI/180)
3270     LET M = (YB-YA)/HN
3280     LET INCPT = YA-M*LAT
3290     LET PHI = LAT
3300     FOOR L=0 TO 10
3310       LET Y(L) = M*PHI+INCPT
3330       LET PHI = PHI+HN
3340     NEXT L
3350     LET SUM = 0
3360     FOR L=1 TO 9
3370       LET SUM = SUM+2*Y(L)
3380     NEXT L
3390     LET INTEGRAL = .5*HN*(Y(0)+SUM+Y(10))
3400     LET DMDTH(I,LAT) = -RHO*2*PI*RE^2*INTEGRAL*.001
3404   NEXT J
3406  NEXT I
3410 RETURN
3500 REM -----------------------------------------------------
3510 REM Subroutine: to calculate dm/dt for large scale eddies
3520 REM -----------------------------------------------------
3530 REM
3540  REM calculate the area of each 1 deg lat band
3550 FOR I=0 TO 89
3560   LET AREA(I)=2*PI*6378000!^2*(SIN((I+1)*PI/180)-SIN(I*PI/1
80))
3570  NEXT I
3580 REM find area of 40-60 deg band and 0-40 + 60-90
3590 LET AREA1 = 2*PI*6378000!^2*(SIN(60*PI/180)-SIN(40*PI/180))
3600 LET AREA2 =  2*PI*6378000!^2-AREA1
3610 FOR I=40 TO 59
```

```
3620   LET DMDTE(I) = 4.05E+16*(AREA(I)/AREA1)/(365*24*3600)
3630  NEXT I
3640 FOR I=0 TO 39
3650   LET DMDTE(I) = 3.95E+16*(AREA(I)/AREA2)/(365*24*3600)
3660  NEXT I
3670 FOR I=60 TO 89
3680   LET DMDTE(I) = 3.95E+16*(AREA(I)/AREA2)/(365*24*3600)
3690  NEXT I
3700 RETURN
4000 REM ----------------------------------------------------
4010 REM SUBROUTINE: To compute the time it takes a particle to
4020 REM fall from its initial injection height to the tropopaus
e.
4030 REM ----------------------------------------------------
4040 REM
4050 REM calculate initial height of Ra wafer
4060 GOSUB 4600
4070 REM calculate dz/dt from stokes law (m/day)
4080 LET H = ((HRA-12000)/2)+12000
4090 GOSUB 9500
4100 LET DZDTS = ((2/9)*(RA*.000001)^2*RHOF*G/N)*3600*24
4110 REM compute average dz/dt (m/day-season) from vert winds

4115 IF T<90 THEN LET TT = .1 ELSE LET TT =1
4120 GOSUB  4800
4130 REM calculate time delay
4140 LET TVW = 00
4150 LET DZ = 0
4155 LET DAYR = DAYO
4160 LET DAYR=DAYR+TT: IF DAYR>365 THEN LET DAYR=DAYR-365
4170 IF DAYR<=59 OR DAYR>=334 THEN LET SEASONR = 1
4180 IF DAYR>59 AND DAYR<=151 THEN LET SEASONR = 2
4190 IF DAYR>151 AND DAY<=243 THEEN LET SEASONR = 3
4200 IF DAYR>243 AND DAYF<334 THEN LET SEASONR = 4
4210 LET TVW = TVW+TT
4215 IF TVW>TF THEN 4216 ELSE 4220
4216 LPRINT"Ra doesn't reach the tropopause before "TF" days"
4217 LPRINT" Current Ra = "RA,"time = "T: STOP
4220 LET DZ = (-AV(SEASONR)+DZDTS)*TT+DZ
4230 IF DZ<(HRA-12000) THEN GOTO 4160
4240 LET DT = TVW-T
4245 IF DT<0 THEN LET DT = 0
4250 RETURN
4600 REM-----------------------------------------------------
4610 REM:  SUBROUTINE: To calculate the initial height of a
4620 REM: particle using Hopkins' center wafer values.
4630 REM----------------------------------------------------
4640 REM
4650 LET C40 = 1.574: LET C41 = -.01197: LET C42 = .03636
4660 LET C43 = -.0041: LET C44 = .00019655
4670 LET LN = LOG(YKT)
```

```
4680 LET SLOPE = -EXP(C40+C41*LN+C42*LN^2+C43*LN^3+C44*LN^4)
4690 LET C50 = 7.889: LET C51 = .34: LET C52 = .001226
4700 LET C53 = -.005227: LET C54 = .000417
4710 LET INCPT = EXP(C50+C51*LN+C52*LN^2+C53*LN^3+C54*LN^4)
4720 LET HRA = SLOPE*(2*RA)+INCPT
4730 RETURN
4800 REM ----------------------------------------------------
4810 REM SUBROUTINE: To compute average dz/dt for particle Ra
4820 REM from initial wafer height to trop per season.
4830 REM ---------------------------------------------------
4840 REM
4850 REM Compute avg dz/dt per season from trop to wafer height
4860 LET HRAKM = INT(HRA/1000)
4870   FOR S=1 TO 4
4880     LET SUM = 0
4890     FOR HZ = 13 TO HRAKM-1
4900       LET SUM = 2*AVWHZ(S,HZ)+SUM

4910      NEXT HZ
4920     LET AV(S)=.5*(AVWHZ(S,12)+SUM+AVWHZ(S,HRAKM))/(HRAKM-12
 )
4930    NEXT S
4940 RRETURN
5500  REM ---------------------------------------------------
5010 REM Subroutine: to compute initial injection  and Ra
5020 REM ----------------------------------------------------
5030 REM
5040 REM Compute cloud top using Connors Equations
5050 LE T C11=1.61324: LET C12=-.0682128: LET C13=.0843986
5055 LET C14 = -.0123826
5060 LET C15 = 6.34405E-04: LET LN = LOG(YKT)
5070 LET HCSLOPE = -EXP(C11+C12*LN+C13*LN^2+C14*LN^3+C15*LN^4)
5080 LET C21=8.106671: LET C22=.302301: LET C23=.0191831
5085 LET C24 = -7.48407E-03
5090 LET C25 = 5.18155E-04
5100 LET HCINCPT = EXP(C21+C22*LN+C23*LN^2+C24*LN^3+C25*LN^4)
5102  LET HUPPER = HCINCPT
5103 IF HUPPER<=HTM THEN 5104 ELSE 5110
5104 PRINT:  PRINT"Cloud does not penetrate stratospherre":STOP
5110 LPRINT: LPRINT "CLOUD TOP = "HUPPER: LPRINT
 5115 LET HRA = HTM
5120 REM Compute Ra at 12 km at t=0 using Hopkins equation
5130 LET C40 = 1.574: LET C41 = -.01197: LET C42 = .03636
5140 LET C43 = -.0041: LET C44 = .0001965
5150 LET  LN = LOG(YKT)
5160 LET SLOPE = -EXP(C40+C41*LN+C42*LN^2+C43*LN^3+C44*LN^4)
5170 LET C50 = 7.889: LET C51 = .34: LET C52 = .001226
5180 LET C53 = -.005227: LET C54 = .000417
5190 LET INCPT = EXP(C50+C51*LN+C52*LN^2+C53*LN^3+C54*LN^4)
5200 LET RA = (HTM-INCPT)/(2*SLOPE)
5310 REM calculate fraction of activity in cloud
```

```
5320 LET R = RA
5330 GOSUB 8500
5340 REM calculate activity
5350 LET TACTIVITY = YKT *.001*FF*100000!
5360 LET ACTSTRAT = TACTIVITY*FRACT
5385 LPRINT "t = "T,"Ra = "RA," Activity Fraction = "FRACT
5386 LPRINT"Total Activity = "TACTIVITY
5387 LPRINT"Stratospheric Activity = "ACTSTRAT
5390 RETURN
5500 REM ------------------------------------------------------
5510 REM Subroutine: to calculate the total dmdt and average
5511 REM air density
5530 REM ------------------------------------------------------
5540 REM
5750 REM calcculate an average air density
5760 LET H = HUPPER: IF HUPPER>84852! THEN LET H = 84852!
5765 GOSUB 9500
5770 LET RHO1 = RHO
5780 LET H = HTM: GOSUB 9500
5790 LET RHO2 = RHO
5795 LET ARHO = (RHO1+RHO2)/2
5800 PRINT"Average Cloud Density = "ARHO" kg/m3"
5820 REM Add the fall from hadley cells and large eddies
5830  FOR S=1 TO 4
5840   FOR I=0 TO 89
5844     IFF DMDTH(S,I)<0 THEN DMDT(S,I)=DMDTE(I) ELSE GOTO 5860
5845       GOTO 5870
5860     LET DMDT(S,I) = DMDTH(S,I)+DMDTE(I)
5870    NEXT I
5880  NEXT S
5890 RETURN
6000 REM ------------------------------------------------------
6010 REM Subroutine: to calculate sigma y, cloud volumes,
6020 REM activity per volume and activity per lat band.
6030 REM ------------------------------------------------------
6040 REM
6050 REM calculate sigma y
6060 LET KKYY = 200000!
6070 LET SIGY = KKYY*T^.5
6080 REM calculate thhe 'X' distance of cloud dispersion
6090 LET X = (360/16)*T
6100 IF X>360 THEN  LET X = 360
6110 REM calculate cloud volume per 1 deg lat band
6135 PRINT"Cloud top = "HUPPER,"Cloud bottem = "HTM:PRINT
6140 REM calculate the y limits in meters
6150 LET SY = BLAT*69*1.6093*1000
6160 REM calculate each vol using step function approximation
6170 LET TVOL = 0
61 90 FOR L=0 TO 89
6200   LET XN = X*COS(L*PI/180)*69*1.60934*1000
```

```
6210   LET YN = -SY+L*69*1.60934*1000
 6220   LET ZN = EXP(-.5*(YN/SIGY)^2)*(HUPPER-HTM)
6230   LET VOL(L) = ZN*XN*69*1.60934*1000*(X/360)
6232   IF VOL(L)<1 THEN LET VOL(L) = 0
6240   LET TVOL = TVOL+VOL(L)
6250  NEXT L
6252 REM calculate the additional volume created by up drafts
6253 GOSUB 6500
6260 REM calcculate the activity per volume of cloud (Ci/m^3)
6270 LET ACTTDEN = ACTSTRAT/(TVOL+TAVOL)
6290 FOR L=0 TO 89
6292   IF VOL(L)=0 THEN 6294 ELSE 6300
6294     LET AACT(L) = 0
6296    GOTO 6320
6300   LET ACT(L) = ACTDEN*(VOL(L)+AVOL(L))
6320  NEXT L
6330 RETURN
6500 REM -----------------------------------------------------
 6511  REM Subroutine: To calculate the volume of air injected
6520 REM into  thhe cloud by the upflow of the Hadley cells.
6533  REM -----------------------------------------------------
6540 REM
6550 LET TAVOL = 0
6560 FOR I=0 TTO 89
6570   IF DMDTH(SEASON,I)<0 THEN 6580 ELSE 6590
6580     LET AVOL(I)=ABS(DMDTH(SEASON,I))*3600*24*FT*(X/360)/ARH
0
6585     GOTO 6594
6590   LET AVOL(I) = 0
6594   LET TAVOL = TAVOL+AVOL(I)
6595  NEXT I
6630 RETURN
7000 REM -----------------------------------------------------
7010 REM Subroutine: to calculate the activity per mass of air
7020 REM -----------------------------------------------------
7030 REM
7100 RREM calculate activity per mass of air per lat band
7110 FOR  I=0 TO 89
7115   IF VOL(I)=0 THEN 7116 ELSE 7120
7116     LET ACTMASS(II) = 0: GOTO 7130
7120   LET ACTMASS(I) = ACT(I)/(ARHO*VOL(I))
7130  NEXT I
7140 RETURN
7500 REM -----------------------------------------------------
7510 REM Subroutine: to calculate fall from cloud
7520 REM -----------------------------------------------------
7530 REM
7540 REM calculate fall in 1 deg bands
7550 FOR I=0 TO 89
7555    IF DMDT(SEASON,I)<0  THEN 7556 ELSE 7560
```

```
7556     LET FALL(I) = 0
7557    GOTO 75800
7560   LET FALL(I) = ACTMASS(II)*DMDT(SEASON,I)*3600*24*FT*(X/360
)
7570   IF FALL((I)>ACT(I) THEN LET FALL(I) = ACT(I)
7580   LET ACTSTRAT = ACTSTRAT-FALL(I)
7590   IF ACTSTRAT<0 THEN LET ACTSTRAT =0
7600  NEXT I
7605 GOSUB 8000
7610 REM compute in 0-10 and 20 deg bands current and total fall
7615 LET LFALL(1) = 0
7620 FOR I=0 TO 9
7630   LET LFALL(1) = LFALL(1)+FALLL(I)
7635   LET TFALL(1) = TFALL(1)+FALL(I)
7640  NEXT I
7650 LET L=9
7660 FOR  I=2 TO 5
7670   LET LFALL(I) = 0
7680   FOR J=1 TO 20
7690     LET L = L+1
7700     LEET LFALL(I) = LFALL(I)+FALL(L)
7705     LET TFALL(I) = TFALL(I)+FALL(L)
7710    NEXT J
7720  NEXT I
7730 RETURN
8000 REM -----------------------------------------------------
8010 REM Subroutine: To commpute new Ra based upon remaining
8020 REM activity aloft using an empirical fit to the
8021 REM to the Activity distribution function.
8030 REM ----------------------------------------------------
8040 REM
8050 REM define coefficients of function
8060 LET C31 = .1929022: LET C32 = 46.7777: LET C33 = -144.9139
8070 LET C34 = 839.8684: LET C35 = -1406.685: LET C36 = 1043.291
8080 REM calculate new fraction of activity aloft
8100 LET FRACT = ACTSTRAT/TACTIVITY
8110 REM calculate new Ra
8120 LET RA = C31+C32*FRACT+C33*FRACT^2+C34*FRACT^3+C35**FRACT^4+
C36*FRACT^5
8125 LET RA = RA+C37*FRACT^6+C38*FRACT^7
8250 PRINT"New Ra = "RA,"New fract aloft = "FRACT
8260 PRINT
8300 RETURN
8500 REM  ----------------------------------------------------
8510 REM Subroutine: to calculate fraction of activity using
8520 REM surface/volume (log-normal) distribution.
8530 REM ----------------------------------------------------
8540 REM
8550 IF R=0 THEN LET FRACT = 0: GOTO 8710
8560 REM Calculate the fraction of activity included in the
```

```
8570 REM particles of radaii 0-r using DELFICC default values
8580 REM and a volume/surface disttributed activity distribution.
8585 LET C1 =.1996854: LET C2 = .115194: LET C3 = .000344
8586 LET C4 = .019527
8590 LET R1 = .204: LET R2 =4: LET FV = .68
8600 LET ALPHAO = LOG(R1): LET BETA = LOG(R2)
8610 LET ALPHA2 = ALPHAO+2*BETA^22: LET ALPHA3 = ALPHAO+3*BETA^2
8620 LET FZ(1) = (LOG(R)-ALPHA3)/BETA
8630 LET FZ(2) = (LOG(R)-ALPHA2)/BETA
8640 FOR I=1 TO 2
8650   LET ZZ = FZ(I)
8660   IF FZ(I)<0 THEN LET ZZ = ABS(FZ(I))
8670   LET F(I) = 1-(1/(2*(1+C1*ZZ+C2*ZZ^2+C3*ZZ^3+C4*ZZ^4)^4))
8680   IF FZ(I)<0 THEN LET F(I) = 1-F(I)
8690  NEXT I
8700 LET FRACT = FV*F(1)+(1-FV)*F(2)
8710 RETURN
9000 REM ---------------------------------------------------
 9010 REM Subroutine: to print output at the appropriate point
9020 REM ---------------------------------------------------
9030 REM
9920  REM print output
9204 LPRINT"------------------------------------------------------"
9205 LPRIINT:LPRINT"Time = "T" days   ";"Season = "SEASON: LPRINT
9206 LPRINT"Current Ra = "RA,"fraction activity aloft = "FRACT
9207 LPRINT"Activity aloft = "ACTSTRAT " Ci":LPRINT
9209 LPRINT"latitude          Current                Total"
9210 LPRINT" band          Fallout(Ci)             Fallout(Ci)"
9220 FOR I=1 TO 5
9230   LPRINT I,LFALL(I),,TFALL(I)
9240  NEXT I
9244  LPRINT"-----------------------------------------------------"
9400 RETURN
9500 REM  ---------------------------------------------------
9510 REM SUBROUTINE: To calculate the U S Standaard Atmosphere
9520 REM values for: Temp(TZ)(deg K), Pressure(PZ)(N/m^3), Air
9530 REM density(RHO)(kg/m^3), dynamic viscosity(N)(kg/sec-m),
9535  REM and acceleration due to gravity (g)(m/sec^2).
9540 REM ---------------------------------------------------
9550 REM
9570   IF H<=11000 THEN 9580 ELSE 9610
9580     LET TZ = 288.15-.006545*H
 9590     LET PZ = 101300!*((288.15/TZ)^(-.034164/.006545))
9600     GOTO 9840
9610   IF H>111000 AND H<=20000 THEN 9620 ELSE 9650
9620     LET TZ = 216.65
9630     LET PZ = 22690!*EXP(-.034164*(H-11000)/216.65)
9640     GOTO 9840
9650   IF H>20000 AND  H<=32000 THEN 9660 ELSE 9690
9660     LET TZ = 216.65+.001*(H-20000)
```

```
9670      LET PZ = 5528*((216.65/TZ)^(.034164/.001))
9680      GOTO 9840
9690    IF H>32000 AND H<=47000! THEN 9700 ELSE 9730
9700      LET TZ = 228.65+.0028*(H-32000)
9710      LET PZ = 888.8*(228.65/TZ)^(.034164/.0028)
9720      GOTO 9840
9730    IF H>47000! AND H<=51000! THEN 9740 ELSSE 9770
9740      LET TZ = 270.65
9750      LET PZ = 115.8*EXP(-.034164*(H-47000!)/270.65)
9760      GOTO 9840
9770    IF H>51000! AND H<=71000! THEN 9780 ELSE 9820
9780      LET TZ = 270.65-.0028*(H-51000!)
9790      LET PZ = 69.89*(270.65/TZ)^(-.134164/.0028)
 9800      GOTO 9840
9810    REM values for 71000 < Z <= 84852
9820    LET TZ = 214.65-.002*(H-71000!)
9830    LET PZ = 4.13*(214.65/TZ)^(-.034164/.002)
9840    LET RHO = .003484*(PPZ/TZ)
9850     LET N = 1.458E-06*TZ^1.5/(TZ+110.4)
9866     LET G = 9.80665*(6356766!/(6356766!+H))
9870 RETURN
```

```
10 REM -----------------------------------------------------------
---
20 REM Subroutine: Input into a file vertical wind data tabl
es
30 REM -----------------------------------------------------------
---
40 REM
50 REM
60 DIM TDATA(4,50,9)
70 REM Vertical wind data tables  (mm/sec)
80 REM Winter
90 DATA -4,-3.85,-3.57,-2.81,-2.15,-1.98,-1.2,-.77,-.47,.22
100 DATA -2.11,-2.17,-1.97,-1.61,-1.24,-1.34,-1.31,-.95,-.44
,.18
110 DATA -1.24,-1.16,-.86,-.68,-.85,-1.32,-1.3,-.92,-.5,-.1
120 DATA -1.28,-.65,.31,.04,-.82,-.95,-.76,-.56,-.32,-.1
130 DATA -.93,-.04,.82,.04,-.82,-.55,-.26,-.15,-.08,.06
140 DATA -.62,.11,.76,-.09,-.63,-.32,-.14,.03,.08,.18
150 DATA -.56,.04,.58,-.01,-.89,-.22,-.1,-.01,.02,.12
160 DATA -.7,.04,.37,.25,-.11,-.19,-.48,-.81,-.03,.65
170 DATA -1.38,-.02,.26,.64,.26,-.14,-1.38,-2.04,-.52,1.44
180 DATA -1.4,-.02,.17,.61,.17,-.14,-.99,-1.35,-.12,.88
190 DATA 0,0,0,0,0,0,0,0,0,0
200 FOR I=50 TO 0 STEP -5
210   FOR J=9 TO 0 STEP -1
220     READ TDATA(1,I,J)
230    NEXT J
240  NEXT I
250 REM Spring
260 DATA -.59,-.67,-.27,.17,.39,.45,.43,.21,.02,--.16
270 DATA -.3,-.45,-.19,.34,.51,.35,.08,-.14,-.28,-.43
280 DATA -.12,-.21,-.11,.16,.27,.14,-.02,-.12,-.25,-.35
290 DATA -.17,.05,.32,.24,-.02,-.04,-.02,-.09,-.19,-.28
300 DATA -.17,.25,.53,.14,-.21,-.13,-.01,-.05,-.14,-.14
310 DATA -.35,.06,.4,.04,-.24,-.15,-.08,-.01,-.04,-.02
320 DATA  -.55,-.1,.31,.05,-.16,-.06,-.04,-.05,-.01,.04
330 DATA -.27,-.05,.15,.13,-.01,.05,-.24,-.4,-.01,.74
340 DATA -.04,.02,.06,.26,.24,.17,-.43,-.88,-.26,1.19
350 DATA -.03,-.05,.01,.23,.33,-.04,-.28,-.36,-.16,.78
360 DATA 0,0,0,0,0,0,0,0,0,0
370 FOR I=50 TO 0 STEP -5
380   FOR J=9 TO 0 STEP -1
390     READ TDATA(2,I,J)
400    NEXT J
410  NEXT I
420 REM Summer
430 DATA 2.82,2.75,1.81,1.49,1.58,1.61,1.57,1.33,.69,.21
440 DATA 2.42,2.09,1.31,.91,.86,.98,1.1,.96,.59,.2
450 DATA 1.68,1.49,1.09,.9,.92,.97,.93,.71,.32,-.02
460 DATA 1.02,.91,.75,.74,.74,.7,.53,.38,.1,-.13
```

```
470 DATA .53,.45,.37,.37,.27,.22,.19,.16,.09,0
480 DATA .08,.07,.11,.05,.04,.04,.07,.08,.06,.09
490 DATA -.1,.02,.12,.06,.05,.1,.08,.04,.05,.05
500 DATA -.13,.04,.14,.15,.12,.04,-.02,.04,.36,.48
510 DATA .05,.11,.12,.15,.07,-.14,.19,.75,1.2,1.61
520 DATA -.09,.03,.08,.17,.05,-.15,.14,.54,.89,1.36
530 DATA 0,0,0,0,0,0,0,0,0,0
540 FOR I=50 TO 0 STEP -5
550   FOR J=9 TO 0 STEP -1
560     READ TDATA(3,I,J)
570    NEXT J
580  NEXT I
590 REM Fall
600 DATA .76,.56,-.08,-.15,-.01,-.1,.08,-.04,-.14,.21
610 DATA 1.48,1.03,.43,.16,.11,-.03,-.03,-.03,.03,.22
620 DATA .77,.66,.47,.32,.14,-.11,-.11,-.02,.05,.1
630 DATA -..02,.28,.63,.44,-.05,-.15,-.09,-.07,-.07,-.04
640 DATA -.14,.35,.71,.25,-.21,-.1,-.01,.01,-.06,0
650 DATA -.24,.17,.49,.11,-.19,-.1,-.05,.06,.02,.07
660 DATA -.52,-.02,.34,.01,-.15,-.07,-.02,-.01,.05,.09
670 DATA -.27,-.03,.18,.18,-.03,-.16,-.28,-.18,.24,.59
680 DATA -.43,.04,.2,.47,.04,-.5,-.5,.16,.89,1.25
690 DATA -.37,-.13,.23,.44,.05,-.52,-.38,.08,.71,.92
700 DATA 0,0,0,0,0,0,0,0,0,0
710 FOR I=50 TO 0 STEP -5
720   FOR J=9 TO 0 STEP -1
730     READ TDATA(4,I,J)
740    NEXT J
750  NEXT I
800 REM put tables into a file

810 OPEN"O",#1,"VWIND.DAT"
820   FOR S=1 TO 4
830     FOR Z=0 TO 50 STEP 5
840       FOR LAT=0 TO 9
850       WRITE#1,TDATA(S,Z,LAT)
860        NEXT LAT
870      NEXT Z
880    NEXT S
900 CLOSE#1
910 END
```

```
10 REM SUBROUTINE: to interpolate the vertical wind tables
20 REM to determine a vertical wind at each 1 km altitude
30 REM -----------------------------------------------------
40 REM
50 DIM TDATA(4,50,9),VWLAT(4,50,9)
60 REM input vertical winds(mm/sec) into memory
70 OPEN"I",#1,"VWIND.DAT"
80   FOR S=1 TO 4
90     FOR HZ=0 TO 50 STEP 5
100        FOR LAT=0 TO 9
110          INPUT#1,TDATA(S,HZ,LAT)
120         NEXT LAT
130       NEXT HZ
140    NEXT S
150 CLOSE#1
160 REM Compute average wind per 1 km alt per 10 deg band
170 FOR S=1 TO 4
180    FOR LAT = 0 TO 9
190     FOR HZ=0 TO 50
200       LET A = HZ MOD 5
210       LET LZ = HZ-A: LET UZ = LZ+5: IF UZ>50 THEN LET UZ=
50
220       LET VWLAT(S,HZ,LAT) = (TDATA(S,UZ,LAT)-TDATA(S,LZ,L
AT))*A/5+TDATA(S,LZ,LAT)
230      NEXT HZ
240    NEXT LAT
250   NEXT S
260 REM put wind data into a data file
270 OPEN"O",#1,"vwlat.dat"
280  FOR S=1 TO 4
290    FOR HZ=0 TO 50
300      FOR LAT=0 TO 9
310         WRITE#1,VWLAT(S,HZ,LAT)
320      NEXT LAT
330      NEXT HZ
340    NEXT S
350 CLOSE#1
360 END
```

The following changes are necessary to the computer code of the report model in order to change the particle distribution from DELFIC default to NRDL-N61.

```
1 LPRINT"This run uses NRDL-N61 particle size distribution."
8060 LET C31 = -3.855758E-02: LET C32 = 2.753097
8061 LET C33 = 6.659841
8065 LET C34 = 49.21278: LET C35 = -54.22077
8066 LET C36 = 1011.273
8070 LET C37 = -2102.943: LET C38 = 1668.546
8120 LET RA = C31+C32*FRACT+C33*FRACT^2+C34*FRACT^3+C35*FRAC
T^4+C36*FRACT^5
8125 LET RA = RA+C37*FRACT^6+C38*FRACT^7
8590 LET R1 = .00039: LET R2 =7.24: LET FV = .68
```

Appendix E: Computer Code Variables and Definitions for Report Model

ACT( )	= The activity per 1 degree volumes in the cloud at time t.
ACTDEN	= The activity per volume ratio across the cloud.
ACTMASS( )	= The activity to mass of air ratio of each 1 degree cloud volume at time t.
ACTSTRAT	= The activity in the stratosphere at time T.
ALPHA0, ALPHA2, ALPHA3	= The values of the alphas in the surface - volume activity distribution.
AREA( )	= The area of each 1 degree latitude band at time t.
AREA1	= Area of the 40-60 degree latitude band.
AREA2	= Area of the Northern hemisphere minus AREA1.
ARHO	= Average air density within cloud.
AV( )	= The average vertical wind velocity per season from the cloud top to the tropopause.
AVOL( )	= The increased volume of air per 1 degree latitude band caused by the Hadley cell upflows.
AVWHZ( )	= The average vertical winds at 1 km altitudes per season.
BDAY	= The day of the month of the burst.
BETA	= Value of beta in the surface - volume activity distribution.
BLAT	= The latitude of the burst.
BLBAND	= The 10 degree latitude band of the burst.
BMONTH$	= The month of the burst.
C__	= Coefficients of appropriate equations.
COUNT	= Counter used to determine when to print output

DAY	= The julian date at time t.
DAYO	= The julian date of the burst.
DAYR	= Counter used to keep track of julian dates of Ra wafer fall to the tropopause.
DMDT( )	= The total mass flux of air per 1 degree latitude band per season.
DMDTE( )	= The mass flux of air across the tropopause per 1 degree latitude band from the large scale eddies.
DMDTH( )	= The mass flux of air across the tropopause per 1 degree latitude band per season from the Hadley cells.
DT	= The delay time added to the current time to account for the actual time of arrival of Ra at the tropopause.
DZ	= Distance Ra wafer falls in time TT.
DZDTS	= The vertical velocity of the Ra particle at time t, as calculated from Stokes law.
F( )	= Dummy variable used in distribution function calculations.
FALL( )	= The fallout that falls per cycle per 1 degree latitude band.
FF	= The fission fraction of the device.
FRACT	= The fraction of activity in the stratosphere at t.
FT	= The time that the cloud is allowed to be transferred across the tropopause per growth period.
FV	= Fraction of activity volume distributed.
FZ( )	= Dummy variable used in distribution function calculations.
G	= Gravitational acceleration at altitude H.
H	= Dummy variable used as height in U.S. Standard Atmosphere subroutine.
HCINCPT	= The intercept of the cloud top equation.
HCSLOPE	= The slope of the cloud top equation.
HN	= The step used for trapezoidal integration.

HRA = The height of the current Ra wafer.

HRAKM = Height of the Ra wafer in kilometers.

HTBURST = The height of the tropopause of the burst.

HTKM = Height of the tropopause in kilometers.

HTM = Height of the tropopause in meters.

HUPPER = Height to cloud top.

HZ = A loop counter.

I = A loop counter.

INCPT = Intercept of the line representing the function to be numerically integrated, and the intercept of the wafer height equations.

INTEGRAL = The value of the integral of trapezoidal integration.

J = A loop counter.

Kkyy = Coefficient of mean horizontal dispersion equation.

L = A loop counter.

LAT = A loop counter.

LFALL( ) = The total fall in t per 20 degree latitude bands

LN = Dummy variable representing the ln(YKT).

M = The slope of the line representing the function to be numerically integrated.

M$( ) = The character string to match the number of days per month to the month.

MDAYS( ) = The number of days in each month.

N = Dynamic Viscosity

PHI = Values on the interval to be integrated over.

PI = The value of the constant pi.

PZ = Pressure variable used in U.S. Standard Atmosphere.

R = Dummy variable used for particle radius for activity fraction calculations.

RA = The largest particle radius aloft at time t. Represents the cloud bottom wafer.

RE = The radius of the earth.

RHO = The density of air at an altitude.

RHOF = Density of fallout particles.

RHO1 = Air density at cloud top.

RHO2 = Air density at tropopause.

R1 = The mean particle radius for the distribution used.

R2 = The standard deviation of the particle size distribution.

S = A loop counter.

SEASON = The season of the year at time t.

SEASONR = Season of the year on DAYR.

SIGY = The mean horizontal dispersion (m) at time t.

SLOPE = The slope of the wafer height equations.

SUM = Dummy variable representing a sum.

SY = The distance from the equator to the burst latitude.

T = Time in days after the burst.

TACTIVITY = The total activity of the burst at t = 0.

TAVOL = The total additional volume of air from the upflow of Hadley cells.

TDATA( ) = The vertical wind tables of winds at 10 degree latitudes and 5 km altitudes, per season. From ref 17.

TF = The time in days to end calculations.

TFALL( ) = The total fall per 1 degree latitude band at time t.

TT = Time step used to find fall time of Ra wafer to tropopause.

TZ	=	Temperature variable used in U.S. Standard Atmosphere.
TVOL	=	Total volume of the cloud at time T.
TVW	=	Counter used to keep track of time of fall of Ra wafer to tropopause.
VWLAT( )	=	The average vertical winds of 10 degree latitude bands and 1 km altitudes, per season.
VOL( )	=	Volume per 1 degree section of cloud at time t.
W(,)	=	The vertical wind values at the tropopause for each 1 degree of latitude per season.
X	=	The distance the cloud travels in degrees around the earth in time t.
XN	=	The length of the 1 degree latitude band in meters.
Y( )	=	Dummy variable used in trapezoidal integration.
YA,YB	=	The lower and upper limits of the function to be numerically integrated.
YN	=	The horizontal displacement location of a 1 degree latitude band.
YKT	=	Device yield in kilotons.
ZN	=	Height of cloud for a 1 degree latitude band.
ZZ	=	Dummy variable used in distribution fraction calculations.

Appendix F: Computer Code Listing of Empirical Model

This appendix contains the computer code listing of the empirical fallout model as developed by K.R. Peterson (15). The code only includes the portions of the model that deal with fallout from surface bursts. The input is menu driven and the output is in kCi of activity of Sr90 per season per 20 degree latitude bands. Since the variables are self explanatory if used in conjunction with (15), no listing of them is included here.

```
10 REM -------------------------------------------------------------
20 REM This program computes fallout in kci per lat band based
30 REMon the model by K.R.Peterson.  Only surface bursts are
30 REM considered in this program.
40 REM -------------------------------------------------------------
50 REM
99 CLEAR
100 DIM TABLE(9,4,9,16),TFALL(9,10)
110 REM input data tables into memory
120 GOSUB 5000
130 REM read input of burst data
140 PRINT"Enter the code for th burst yield (MT) below:"
150 PRINT
160 PRINT"Yield   Code     Yield   Code     Yield     Code"
165 PRINT".03  -   0"
170 PRINT".05  -   1        .07   -   2       .1     -    3"
180 PRINT".2   -   4        .3    -   5       .5     -    6"
190 PRINT".7   -   7         1    -   8        2     -    9"
200 PRINT"3    -  10         5    -  11        7     -   12"
210 PRINT"10   -  13        20    -  14       30     -   15"
220 PRINT"50   -  16"
230 INPUT Y
240 PRINT
250 PRINT
260 PRINT"Enter the code for equatorial or polar burst:"
270 PRINT"     Equatorial(0 - 30 deg N) : 1 "
280 PRINT"     Polar (30 - 90 deg N)     : 2 "
285 INPUT LOCATION
290 PRINT
300 INPUT"Enter fission fraction";FF
310 PRINT
320 PRINT
330 PRINT"Enter code for season of burst"
340 PRINT
350 PRINT"Dec - Feb: 1"
360 PRINT"Mar - May: 2 "
370 PRINT"Jun - Aug: 3"
380 PRINT"Sep - Nov: 4"
390 INPUT SEASON1
400 IF SEASON1=2 OR SEASON1=3 THEN SEASON2=1 ELSE SEASON2=2
410 REM check for location of burst and calculate fallout
420 IF LOCATION=1 THEN 500 ELSE 1000
490 GOTO 2000
500 REM compute fallout for equatorial burst
510 LET LES = TABLE(2,1,1,Y)*.5*FF
520 LET UES = TABLE(2,1,2,Y)*.5*FF
530 LET HEA = TABLE(2,1,3,Y)*.5*FF
535 LET TCI = LES+UES+HEA
540 FOR I=1 TO 9
550   FOR J=1 TO 8
```

```
560     LET FLES = TABLE(4,SEASON1,I,J)*LES
570     LET FUES = TABLE(5,SEASON1,I,J)*UES
580     IF SEASON1=1 OR SEASON1=3 THEN N=1 ELSE N=0
590     LET FHEA = TABLE(6,SEASON2,I,J+N)*HEA
600     TFALL(I,J) = FLES+FUES+FHEA
620    NEXT J
630  NEXT I
640 GOTO 2000
1000 REM compute fallout for a polar burst
1010 LET LPS = TABLE(2,2,1,Y)*.5*FF
1020 LET UPS = TABLE(2,2,2,Y)*.5*FF
1030 LET HPA = TABLE(2,2,3,Y)*.5*FF
1035 LET TCI = LPS+UPS+HPA
1040 FOR I=1 TO 9
1050   FOR J=1 TO 8
1060     LET FLPS = TABLE(7,SEASON1,I,J)*LPS
1070     LET FUPS = TABLE(8,SEASON1,I,J)*UPS
1080     IF SEASON1=1 OR SEASON1=3 THEN N=1 ELSE N=0
1090     LET FHPA = TABLE(9,SEASON2,I,J+N)*HPA
1100     LET TFALL(I,J) = FLPS+FUPS+FHPA
1120    NEXT J
1130  NEXT I
2000 REM print output
2010 LPRINT
2020 LPRINT"fallout(kCi) for Yield = ____MT"
2021 LPRINT"Fission fraction = "FF
2022 LPRINT"At location and Season = ________________"
2025 LPRINT"Total injection = "TCI" MCi
2030 LPRINT
2035 LPRINT"season"
2040 LPRINT" after  90 --------- Lat Bands --------- -90"
2050 LPRINT"Burst 1     2     3     4     5     6     7     8
 9     TOT"
2053 LPRINT"-----------------------------------------------------
--------------"
2055 LET I = SEASON1
2060 FOR J = 1 TO 8
2065   LPRINT I;
2068   LET SUM=TFALL(1,J)+TFALL(2,J)+TFALL(3,J)+TFALL(4,J)+TFALL(
5,J)         +TFALL(6,J)+TFALL(7,J)+TFALL(8,J)+TFALL(9,J)
2070   LPRINT USING "###.##";TFALL(1,J),TFALL(2,J),TFALL(3,J),TFA
LL(4,J), TFALL(5,J),TFALL(6,J),TFALL(7,J),TFALL(8,J),TFALL(9,J),S
UM
2080   LET I = I+1: IF I=5 THEN LET I=1
2090  NEXT J
2100 INPUT"enter 1 to redo program";Q
2110 IF Q=1 THEN GOTO 130
2200 END
5000 REM -------------------------------------------------
5010 REM The following are the data tables used to provide
```

```
5020 REM the empirical basis of the model.
5030 REM ------------------------------------------------------
5040 REM
5050 REM Partitioning of Sr90 from equatorial airbursts(fission Y
ield=total Yield)
5200 DATA .001,.0002,.0003,.002,.004,.01,.018,.035,.145,.276,.443
,.497,.525,.3,.21,.05
5210 DATA 0,0,0,0,0,0,0,0,0,0,.055,.203,.475,1.7,2.79,4.95
5220 DATA 0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0
5230 FOR I=1 TO 3
5240     FOR J=1 TO 16
5250         READ TABLE(2,1,I,J)
5260       NEXT J
5270   NEXT I
5300 REM
5310 REM Partitioning of Sr90 from polar airbursts(fission yield=
total yield)
5370 DATA .0001,.0005,.002,.002,.006,.013,.034,.062,.099,.16,.145
,.095,.056,.006,0,0,0
5380 DATA 0,0,0,0,0,0,0,0,0,.04,.155,.405,.644,.994,2,3,5
5390 DATA 0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0
5400 FOR I=1 TO 3
5410     FOR J=0 TO 16
5420         READ TABLE(2,2,I,J)
5430       NEXT J
5440   NEXT I
5500 REM
5510 REM Surface deposition(kCi) for a 1MT injection during Dec-F
eb into the
5520 REM lower stratosophere(17-24km)
5530 DATA .4,4.1,1.2,.6,.6,1.4,.4,.2,.2,.5
5540 DATA 5.2,46,13.9,6.6,6.8,16,4.9,2.3,2.4,5.6
5550 DATA 11.2,98.9,30.3,14.2,14.6,34.3,10.7,5,5.2,12.1
5560 DATA 14.4,23.9,31,7.4,10.5,13.9,10.9,2.6,3.7,4.9
5570 DATA 14,30.7,23.9,25.2,6.6,18.5,8.4,8.9,2.3,6.5
5575 DATA 5.6,32.8,25.8,9.9,3.3,10.7,9.1,3.5,1.2,3.8
5580 DATA 7.8,24.6,19.3,21.3,14.2,6.4,6.8,7.5,5,2.3
5585 DATA 4,12.4,9.6,10.6,7.1,3.3,3.4,3.7,2.5,1.2
5590 DATA 0,0,0,.1,0,0,0,0,0,0
5620 FOR I=1 TO 9
5630     FOR J=1 TO 10
5640        READ TABLE(4,1,I,J)
5650      NEXT J
5660   NEXT I
5700 REM
5710 REM Surface deposition(kCi) for a 1MT injection during Mar -
May into the
5720 REM lower equatorial stratosphere(17-24km)
5730 DATA .6,1.9,2.2,.9,2.6,.6,.8,.3,.9,.2
5740 DATA 7.8,21.9,25.1,10.3,28.8,7.2,8.9,3.6,10.2,2.5
```

```
5750 DATA 16.8,47.1,54.1,22.3,61.9,15.6,19.1,7.9,21.9,5.5
5760 DATA 21.6,11.4,13,16,25.1,16,4.6,5.6,8.9,5.6
5770 DATA 21,14.6,16.7,9.9,33.3,12.4,5.9,3.5,11.8,4.4
5780 DATA 8.4,15.6,17.9,5,19.3,13.3,6.3,1.8,6.8,4.7
5790 DATA 11.7,11.7,13.5,21.5,11.4,10,4.8,7.6,4,3.5
5800 DATA 6,5.9,6.8,10.9,5.7,5,2.4,3.8,2,1.8
5810 DATA 0,0,0,.1,0,0,0,0,0,0
5820 FOR I=1 TO 9
5830     FOR J=1 TO 10
5840         READ TABLE(4,2,I,J)
5850       NEXT J
5860   NEXT I
5900 REM
5910 REM Surface deposition(kCi) for a 1MT injection during June-
Aug into the
5920 REM lower equatorial stratosophere(17-24km)
5930 DATA .2,2.1,1.5,3.2,.7,.5,.5,1.1,.3,.2
5940 DATA 2.6,23.7,16.4,34.8,8.1,5.6,5.8,12.3,2.9,2
5950 DATA 5.6,51,35.4,74.8,17.6,12.1,12.5,26.4,6.2,4.3
5960 DATA 7.2,12.3,25.4,30.4,18,6.3,9,10.7,6.4,2.2
5970 DATA 7,15.8,15.7,40.3,13.9,21.5,5.6,14.2,4.9,7.6
5980 DATA 2.8,16.9,7.9,23.3,15,8.5,2.8,8.2,5.3,3
5990 DATA 3.9,12.7,34.2,13.8,11.2,18.2,12.1,4.9,4,6.4
6000 DATA 2,6.4,17.3,6.9,5.6,9.1,6.1,2.5,2,3.2
6010 DATA 0,0,.2,0,0,.1,0,0,0,0
6020 FOR I=1 TO 9
6030     FOR J=1 TO 10
6040         READ TABLE(4,3,I,J)
6050       NEXT J
6060   NEXT I
6070 REM
6100 REM
6110 REM Surface deposition for injection during Sept-Nov into lo
wer
6120 REM equatorial stratosophere
6130 DATA .3,2.2,3.7,.9,.5,.5,1.3,.3,.2,.2
6140 DATA 3.9,25.1,40.4,10.4,6,6.3,14.3,3.7,2.1,2.2
6150 DATA 8.4,54.1,86.8,22.5,13.1,13.5,30.6,7.9,4.6,4.8
6160 DATA 10.8,13,35.3,23,6.8,9.7,12.5,8.1,2.4,3.4
6170 DATA 10.5,16.7,46.7,17.8,23.2,6,16.5,6.3,8.2,2.1
6180 DATA 4.2,17.9,27,19.2,9.2,3,9.5,6.8,3.2,1.1
6190 DATA 5.9,13.5,16,14.3,19.7,13.1,5.6,5,7,4.6
6200 DATA 3,6.8,8,7.2,9.8,6.6,2.8,2.5,3.5,2.3
6210 DATA 0,0,0,0,.1,0,0,0,0,0
6215 FOR I=1 TO 9
6220   FOR J=1 TO 10
6230     READ TABLE(4,4,I,J)
6240    NEXT J
6250  NEXT I
6300 REM
```

```
6310 REM Surface deposition for injection during Dec-Feb into the
 Upper
6320 REM equatorial stratosophere(24-50km)
6330 DATA 0,.4,.3,.3,.4,1.4,.5,.3,.3,1,.4,.2,.2
6340 DATA 0,4.6,3.3,2.8,4.6,16,5.8,3.3,4,11.2,4.1,2.3,2.8
6350 DATA 0,9.9,7.2,6,9.8,34.3,12.7,7.1,8.7,24.2,9,5,6.2
6360 DATA 0,2.4,5.9,3.2,7.1,13.9,12.9,3.7,6.2,9.8,9.1,2.6,4.4
6370 DATA 0,2.7,4.4,4.7,4.8,9.7,9,4.9,4,6.9,6.4,3.5,2.8
6380 DATA 0,1.1,5.3,11.4,6.7,5.6,9.5,13.4,7.4,3.9,6.7,9.5,5.2
6390 DATA 0,4.5,7.4,28,7.4,10.7,13.1,33,7.8,7.6,9.3,23.3,5.5
6400 DATA 0,2.1,3.4,13,4.8,4.9,6.1,15.4,4.3,3.5,4.3,10.9,3
6410 DATA 0,.2,.3,1.2,.4,.4,.5,1.4,.4,.4,.4,1,.3
6420 FOR I=1 TO 9
6430   FOR J=1 TO 13
6440     READ TABLE(5,1,I,J)
6450    NEXT J
6460  NEXT I
6500 REM
6510 REM Surface deposition for injection during Mar-May into the
 upper
6520 REM equatorial stratosphere
6530 DATA 0,.2,.4,.3,1.3,.4,.7,.3,1.1,.3,.5,.2,.8
6540 DATA 0,1.6,4.5,3.3,14.6,5.4,8,3.8,12.9,3.8,5.7,2.7,9.1
6550 DATA 0,3.5,9.6,7.1,31.3,11.7,17.1,8.4,27.7,8.2,12.1,5.9,19.6
6560 DATA 0,.9,2.3,5.1,12.7,12,4.1,6,11.2,8.4,2.9,4.2,7.9
6570 DATA 0,1.3,4,4.2,6.4,8.4,5.4,4.9,5.6,6,3.9,3.5,4
6580 DATA 0,1.2,7.9,9.2,4.3,9.2,14.1,10.9,3.8,6.4,10,7.7,2.7
6590 DATA 0,5.1,19.5,9,8.4,12.8,34.5,10.6,7.3,9.1,24.4,7.5,5.2
6600 DATA 0,2.4,9.1,4.2,3.8,6,16.1,5,3.3,4.2,11.4,3.5,2.3
6610 DATA 0,.2,.8,.4,.3,.5,1.5,.4,.3,.4,1.1,.3,.2
6620 FOR I=1 TO 9
6630   FOR J=1 TO 13
6640     READ TABLE(5,2,I,J)
6650    NEXT J
6660  NEXT I
6700 REM
6710 REM Surface deposition for injection during June-Aug into th
e upper
6720 REM equatorial stratosphere
6730 DATA 0,.2,.3,1.2,.4,.4,.5,1.4,.4,.4,.4,1,.3
6740 DATA 0,2.1,3.4,13,4.8,4.9,6.1,15.4,4.3,3.5,4.3,10.9,3
6750 DATA 0,4.5,7.4,28,7.4,10.7,13.1,33,7.8,7.6,9.3,23.3,5.5
6760 DATA 0,1.1,5.3,11.4,6.7,5.6,9.5,13.4,7.4,3.9,6.7,9.5,5.2
6770 DATA 0,2.3,4,6.3,5.1,8.3,8,6.2,4,5.9,5.7,4.4,2.8
6780 DATA 0,2.4,5.9,3.2,7.1,13.9,12.9,3.7,6.2,9.8,9.1,2.6,4.4
6790 DATA 0,9.9,7.2,6,9.8,34.3,12.7,7.1,8.7,24.2,9,5,6.2
6800 DATA 0,4.6,3.3,2.8,4.6,16,5.8,3.3,4,11.2,4.1,2.3,2.8
6810 DATA 0,.4,.3,.3,.4,1.4,.5,.3,.3,1,.4,.2,.2
6820 FOR I=1 TO 9
6830   FOR J=1 TO 13
```

```
6840     READ TABLE(5,3,I,J)
6850    NEXT J
6860  NEXT I
6900 REM
6910 REM Surface deposition for injection during Sept-Nov into the upper
6920 REM equatorial stratosphere
6930 DATA 0,.2,.8,.4,.3,.5,1.5,.4,.3,.4,1.1,.3,.2
6940 DATA 0,2.4,9.1,4.2,3.8,6,16.1,5,3.3,4.2,11.4,3.5,2.3
6950 DATA 0,5.1,19.5,9,8.4,12.8,34.5,10.6,7.3,9.1,24.4,7.5,5.2
6960 DATA 0,1.2,7.9,9.2,4.3,9.2,14.1,10.9,3.8,6.4,10,7.7,2.7
6970 DATA 0,1.4,4.9,5.2,6.4,7.5,7.6,6.1,5.6,5.3,5.4,4.3,4
6980 DATA 0,.9,2.3,5.1,12.7,12,4.1,6,11.2,8.4,2.9,4.2,7.9
6990 DATA 0,3.5,9.6,7.1,31.3,11.7,17.1,8.4,27.7,8.2,12.1,5.9,19.6
7000 DATA 0,1.6,4.5,3.3,14.6,5.4,8,3.8,12.9,3.8,5.7,2.7,9.1
7010 DATA 0,.2,.4,.3,1.3,.4,.7,.3,1.1,.3,.5,.2,.8
7020 FOR I=1 TO 9
7030   FOR J=1 TO 13
7040     READ TABLE(5,4,I,J)
7050    NEXT J
7060  NEXT I
7100 REM
7110 REM Surface deposition for injection during Mar-Aug into the high
7120 REM equatorial stratosophere
7130 DATA 0,0,0,0,0,0,0,.1,.1,.4,.1,.2,.3
7140 DATA 0,0,0,0,0,0,0,.3,2.6,3.6,1.7,3.3,8.7
7150 DATA 0,0,0,0,0,0,0,1.2,7.1,2.8,1.8,12,23.7
7160 DATA 0,0,0,0,0,0,0,.5,2.4,1.3,1,4.3,8.1
7170 DATA 0,0,0,0,0,0,0,.1,.4,.5,.8,1.1,1.2
7180 DATA 0,0,0,0,0,1.4,5.1,3.1,2.9,13.7,25.4,7.9,4.1
7190 DATA 0,0,0,0,0,3.9,15,7,5,38,74.7,17.6,7.1
7200 DATA 0,0,0,0,0,1,5.6,9,4.7,10,27.6,22.6,6.7
7210 DATA 0,0,0,0,0,.1,.1,1,.3,.8,.9,2.6,.4
7220 FOR I=1 TO 9
7230   FOR J=1 TO 13
7240     READ TABLE(6,1,I,J)
7250    NEXT J
7260  NEXT I
7300 REM surface deposition for injection during sept-feb into the high
7310 REM equatorial atmosophere(above 50 km)
7320 DATA 0,0,0,0,0,.1,.1,1,.3,.8,.9,2.6,.4
7330 DATA 0,0,0,0,0,1,5.6,9,4.7,10,27.6,22.6,6.7
7340 DATA 0,0,0,0,0,3.9,15,7,5,38,74.7,17.6,7.1
7350 DATA 0,0,0,0,0,1.4,5.1,3.1,2.9,13.7,25.4,7.9,4.1
7360 DATA 0,0,0,0,0,0,0,.1,.4,.5,.8,1.1,1.2
7370 DATA 0,0,0,0,0,0,0,.5,2.4,1.3,1,4.3,8.1
7380 DATA 0,0,0,0,0,0,0,1.2,7.1,2.8,1.8,12,23.7
7390 DATA 0,0,0,0,0,0,0,.3,2.6,3.6,1.7,3.2,8.7
```

```
7400 DATA 0,0,0,0,0,0,0,.1,.1,.4,.1,.2,.3
7410 FOR I=1 TO 9
7420   FOR J=1 TO 13
7430     READ TABLE(6,2,I,J)
7440    NEXT J
7450  NEXT I
7500 REM surface deposition for injection during dec-feb into low
er polar
7510 REM stratosphere(9-17 km)
7520 DATA 2.7,6.9,5.4,.9,1.5,2.3,1.3,.2
7530 DATA 28.6,66,51.1,18,15,13.5,12.1,3.4
7540 DATA 49.4,250.3,39.9,20,21.5,25.9,9.4,3.8
7550 DATA 15.2,91.7,18.3,12,16.2,19.1,4.3,2.3
7560 DATA 2.3,10.6,3.5,5.1,9.2,5.6,.8,1
7570 DATA 2.9,5.5,2.5,3.3,1,.5,.6,.6
7580 DATA .7,2.7,4.3,2.9,1.2,.5,1,.5
7590 DATA .5,.7,1,.7,.2,.2,.2,.1
7595 DATA 0,0,.1,0,0,0,0,0
7600 FOR I=1 TO 9
7610   FOR J=1 TO 8
7620     READ TABLE(7,1,I,J)
7630    NEXT J
7640  NEXT I
7700 REM Surface deposition for injection during mar-may into the
 lower polar
7710 REM stratosphere
7720 DATA 4.3,1.9,2.2,2,1.8,2.7,.4,.3
7730 DATA 44.6,18.5,25,39.7,55.1,25.6,4.7,7.5
7740 DATA 77.2,70,50,77.4,150.1,19.9,9.5,14.6
7750 DATA 23.8,21.5,20,35,51.1,9.1,3.8,6.6
7760 DATA 3.5,3,6,3,4.6,1.8,1.1,.6
7770 DATA 2,1.6,3,2.3,1,1.3,.6,.4
7780 DATA .5,.8,5.3,2,1.5,1.1,1.4,.4
7790 DATA .7,.2,1.7,.7,1.4,.5,.3,.1
7800 DATA 0,0,.1,0,0,0,0,0
7810 FOR I=1 TO 9
7820   FOR J=1 TO 8
7830     READ TABLE(7,2,I,J)
7840    NEXT J
7850  NEXT I
7900 REM Surface deposition for injection during june-aug into th
e lower polar
7910 REM stratosphere
7920 DATA 1.8,1.9,1.8,2.1,3.8,.3,.4,.4
7930 DATA 18.9,17.9,34.3,64.2,35.8,6.3,9.1,12.1
7940 DATA 32.6,67.9,129.9,175.1,27.9,7,9.7,33.1
7950 DATA 10.1,24.9,47.6,59.6,12.8,4.2,6.5,11.3
7960 DATA 1.5,2.9,5.5,5.3,2.5,1.8,3.7,1
7970 DATA 1.9,1.5,2.9,1.1,1.8,1.2,.4,.2
7980 DATA .5,.7,1.4,3.4,3,1,.5,.6
```

```
7990 DATA .3,.2,.3,1.6,.7,.2,.1,.1
8000 DATA 0,0,0,.1,.1,0,0,0
8010 FOR I=1 TO 9
8020   FOR J=1 TO 8
8030     READ TABLE(7,3,I,J)
8040    NEXT J
8050  NEXT I
8100 REM Surface deposition for injection during sept-nov into th
e lower polar
8110 REM stratosphere
8120 DATA 2.3,2.1,2.4,4.3,.4,.7,1,.6
8130 DATA 24,39.3,73.4,40.9,8.1,7,5.8,3
8140 DATA 41.5,149,200.1,31.9,9,10,11.1,2.8
8150 DATA 12.8,54.6,68.1,14.6,5.4,7.8,8.2,2.5
8160 DATA 1.9,6.3,6.1,2.8,2.3,4.4,2.4,.5
8170 DATA 2.4,3.3,1.3,2,1.5,.5,.2,.1
8180 DATA .6,1.6,3.9,3.4,1.3,.6,.2,.1
8185 DATA .4,.4,1.8,.8,.3,.1,.1,.1
8190 DATA 0,0,.1,.1,0,0,0,0
8210 FOR I=1 TO 9
8220   FOR J=1 TO 8
8230     READ TABLE(7,4,I,J)
8240    NEXT J
8250  NEXT I
8300 REM Surface deposition for injection during dec-feb into the
 upper polar
8310 REM stratosphere(17-50 km)
8320 DATA .2,.6,1.6,.6,1.3,1.9,2,.5,.9,1.2,1.3,.3,.5,.8
8330 DATA .7,5.8,15,11.4,15,18.1,18.9,9,10,11.4,11.9,5.7,6.5,7.2
8340 DATA 2,21.8,11.8,12.7,25.8,68.8,14.8,10,16.3,43.3,9.3,6.3,10
.2,27.3
8350 DATA .5,5.2,5.4,7.6,17.4,16.6,6.8,6,10.9,10.4,4.3,3.8,6.9,6.
6
8360 DATA 0,.3,.5,1.7,1,1,.9,1.5,.8,.6,.5,1,.5,.4
8370 DATA 0,.1,.6,2.3,1.2,.8,3.2,5.3,1.5,.8,2,3.4,1,.5
8380 DATA 0,.2,.2,6.6,2.7,1.1,8.6,15.7,3.4,2.1,5.5,9.9,2.1,1.3
8390 DATA 0,0,.5,2.4,3.4,.6,2.3,5.8,4.3,.6,1.4,3.6,2.7,.4
8400 DATA 0,0,0,.1,.4,.1,.3,.2,.5,.1,.2,.1,.3,.1
8410 FOR I=1 TO 9
8420   FOR J=1 TO 14
8430     READ TABLE(8,1,I,J)
8440    NEXT J
8450  NEXT I
8500 REM Surface deposition for injection during mar-may into the
 upper polar
8510 REM stratosphere
8520 DATA .8,.1,.4,1,1.3,.4,.6,.7,.8,.2,.4,.4,.5,.1
8530 DATA 1.4,1.1,5.1,17.4,40.7,3.5,6.4,13.7,25.6,2.2,4,8.6,16.1,
1.4
8540 DATA 3,4.2,10.1,33.9,110.8,13.3,12.8,26.7,69.8,8.3,8,16.8,44
```

```
,5.2
8550 DATA .8,1.3,4.1,19.1,37.7,4.1,5.1,12.1,23.8,2.6,3.2,7.6,15,1
.6
8560 DATA 0,.1,.7,.8,1.8,.4,1.1,.7,1.3,.3,.7,.4,.8,.2
8570 DATA 0,.2,1.1,.7,.7,2.3,5.7,1.7,.8,2.1,3.6,1,.5,1.3
8580 DATA 0,.6,3.3,1.5,1.1,6.1,16.7,3.6,1.4,5.8,10.5,2.3,.9,3.7
8590 DATA 0,.1,1.2,1.9,1,1.6,6.1,4.6,1.2,1.5,3.9,2.9,.8,.9
8600 DATA 0,0,0,.2,.1,.2,.2,.5,.1,.2,.1,.3,0,.1
8610 FOR I=1 TO 9
8620   FOR J=1 TO 14
8630     READ TABLE(8,2,I,J)
8640    NEXT J
8650  NEXT I
8660 REM Surface deposition for injection during june-aug into th
e upper polar
8670 REM stratosphere
8680 DATA .1,.1,.7,.9,2.8,.4,.6,.7,1.8,.2,.4,.5,1.1,.1
8690 DATA .4,1.1,7,28.4,26.7,3.4,8.8,22.3,16.8,2.2,5.6,14.1,10.6,
1.4
8700 DATA 1.5,4.1,26.6,77.3,20,8,13,33.5,60.9,13.1,8.2,21.1,38.3,
8.2,5.2
8710 DATA .3,1.5,9.7,26.3,9.5,4.7,12.3,20.7,6,3,7.7,13.1,3.8,1.9
8720 DATA 0,.1,.6,1.3,1.1,.5,.9,1.3,.8,.4,.4,.8,.5,.3
8730 DATA 0,.3,.4,.7,2.4,3.1,1.9,1.7,3,2.9,1.2,1,1.9,1.8
8740 DATA 0,1.2,.8,1.2,3.6,12.7,4.1,2.8,4.5,12,2.6,1.7,2.8,7.6
8750 DATA 0,.3,1,1.1,3.3,3.3,5.2,2.5,4.2,3.2,3.3,1.6,2.7,2
8760 DATA 0,0,.1,.1,.6,.4,.6,.1,1,.3,.4,.1,.5,.2
8770 FOR I=1 TO 9
8780   FOR J=1 TO 14
8790     READ TABLE(8,3,I,J)
8800    NEXT J
8810  NEXT I
8900 REM Surface deposition for injection during sept-nov inot th
e upper polar
8910 REM stratosphere
8920 DATA .2,.3,.6,2.3,.4,.6,.8,1.8,.2,.4,.5,1.2,.1,.2
8930 DATA .6,2.9,18.4,22.2,7.4,9.2,23.2,17.4,4.7,5.8,14.6,11,2.9,
3.7
8940 DATA 1.7,11.1,50.2,17.3,8.2,35,63.3,13.6,5.2,22,39.9,8.6,3.3
,13.9
8950 DATA .4,4.1,17.1,7.9,5,12.8,21.5,6.2,3.1,8.1,13.6,3.9,2,5.1
8960 DATA 0,.2,.8,.8,1.2,.7,1.2,.7,1,.5,.7,.5,.6,.3
8970 DATA 0,.1,.2,1.3,4.8,.7,1.3,3.1,6.1,.7,.8,1.9,3.8,.4
8980 DATA 0,.2,.7,2.9,14.1,2.3,3.3,6.8,17.8,2.1,2.1,4.3,11.2,1.3
8990 DATA 0,.1,.3,1.5,5.2,.6,1.6,3.5,6.5,.6,1,2.2,4.1,.4
9000 DATA 0,0,0,.1,.2,.1,.2,.3,.2,.1,.1,.2,.1,.1
9020 FOR I=1 TO 9
9030   FOR J=1 TO 14
9040     READ TABLE(8,4,I,J)
9050    NEXT J
```

```
9060  NEXT I
9100 REM Surface deposition for injection during mar-aug into the
 high polar
9110 REM atmosphere (above 50 Km)
9120 DATA 0,0,0,0,0,0,0,.1,.3,.9,.3,.5,.7
9130 DATA 0,0,0,0,0,0,0,.8,6.1,8.4,4,7.4,20.3
9140 DATA 0,0,0,0,0,0,0,2.8,16.5,6.5,4.3,28.1,55.2
9150 DATA 0,0,0,0,0,0,0,1.1,5.6,2.9,2.4,10.1,18.8
9160 DATA 0,0,0,0,0,0,0,.1,.4,.5,.8,1.1,1.2
9170 DATA 0,0,0,0,0,.7,2.4,1.5,1.3,6.4,11.9,3.7,1.9
9180 DATA 0,0,0,0,0,1.8,7,3.3,2.3,17.7,34.9,8.2,3.3
9190 DATA 0,0,0,0,0,.5,2.6,4.2,2.2,4.7,12.9,10.5,3.1
9200 DATA 0,0,0,0,0,.1,.1,.5,.1,.4,.4,1.2,.2
9210 FOR I=1 TO 9
9220   FOR J=1 TO 13
9230     READ TABLE(9,1,I,J)
9240    NEXT J
9250  NEXT I
9300 REM Surface deposition for injection during sept-feb into th
e high polar
9310 REM atmosophere(above 50 km)
9320 DATA 0,0,0,0,0,.1,.1,.9,.3,.6,.8,2.4,.4
9330 DATA 0,0,0,0,0,.9,5.2,8.4,4.4,9.3,25.7,21,6.3
9340 DATA 0,0,0,0,0,3.6,14,6.5,4.7,35.4,69.6,16.4,6.7
9350 DATA 0,0,0,0,0,1.3,4.8,2.9,2.7,12.8,23.7,7.3,3.9
9360 DATA 0,0,0,0,0,0,0,.1,.4,.5,.8,1.1,1.2
9370 DATA 0,0,0,0,0,0,0,.5,2.8,1.5,1.2,5.1,9.4
9380 DATA 0,0,0,0,0,0,0,1.4,8.3,3.3,2.1,14.1,27.7
9390 DATA 0,0,0,0,0,0,0,.4,3.1,4.2,2,3.7,10.2
9400 DATA 0,0,0,0,0,0,0,.1,.1,.5,.1,.2,.3
9410 FOR I=1 TO 9
9420   FOR J=1 TO 13
9430     READ TABLE(9,2,I,J)
9440    NEXT J
9450  NEXT I
9460 RETURN
```

Appendix G: Additional Graphs of Data

This appendix contains additional graphs of data based upon different input conditions than is used for the data discussed in Chapter V. The data is arranged in sets of common input parameters. Comparisons of the radius aloft (Ra) and the fraction of activity in the stratosphere at time t are included. The purpose of this appendix is to show the consistency of the data from different input conditions.

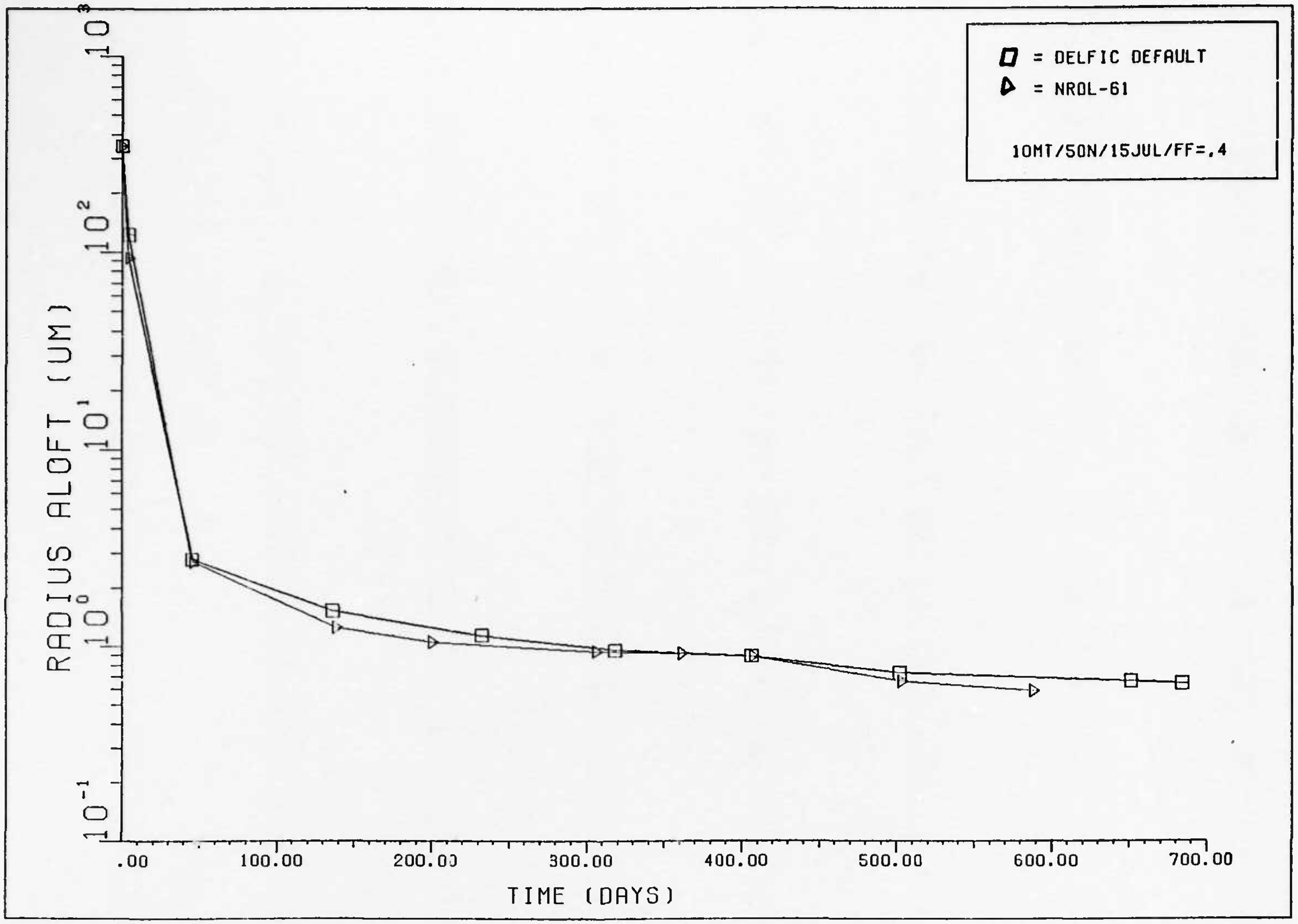

Figure G1. Data Set 1 - Comparison of Ra at Time t

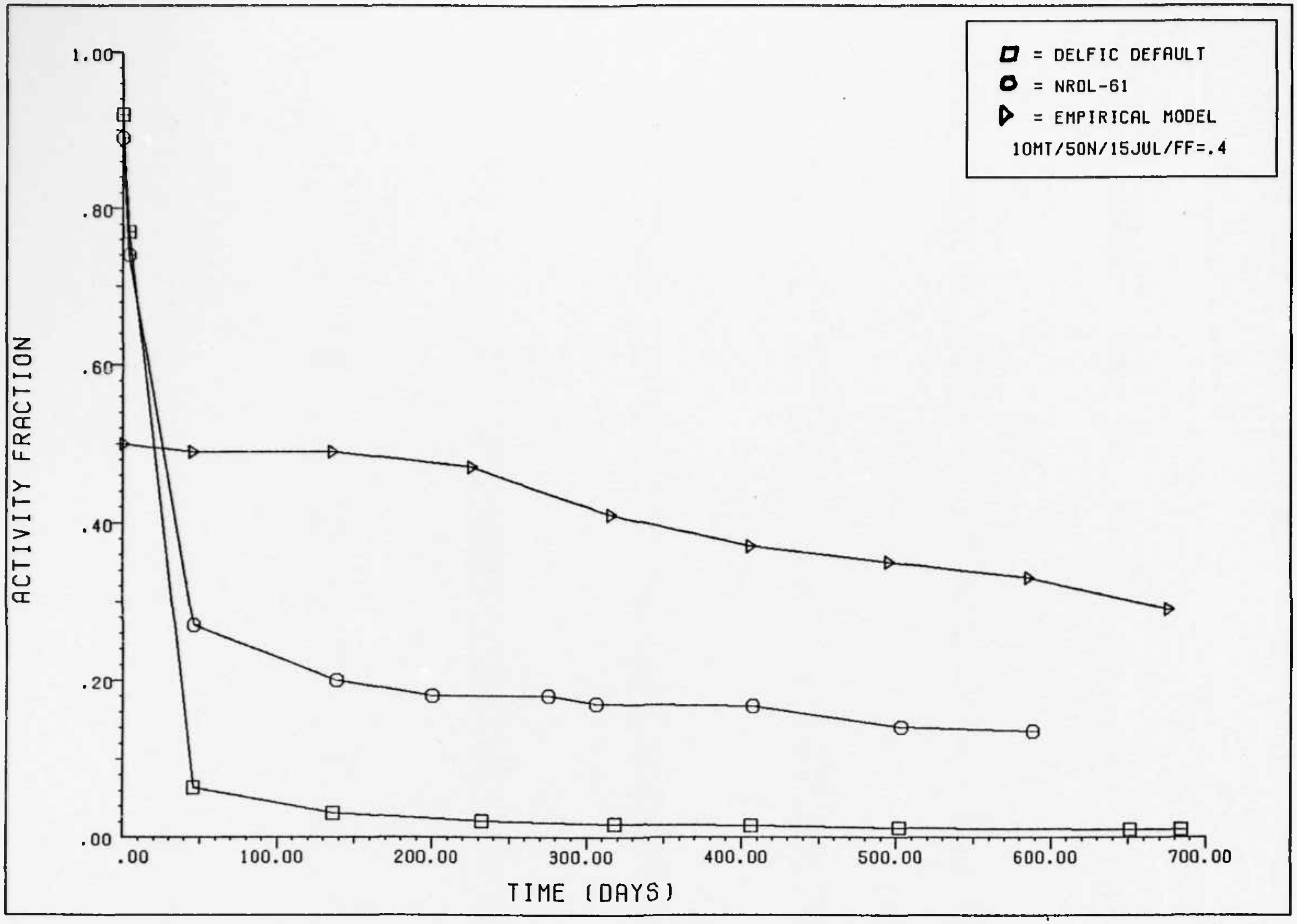

Figure G2. Data Set 1 - Comparison of Activity Fraction Remaining in the Stratosphere at Time t

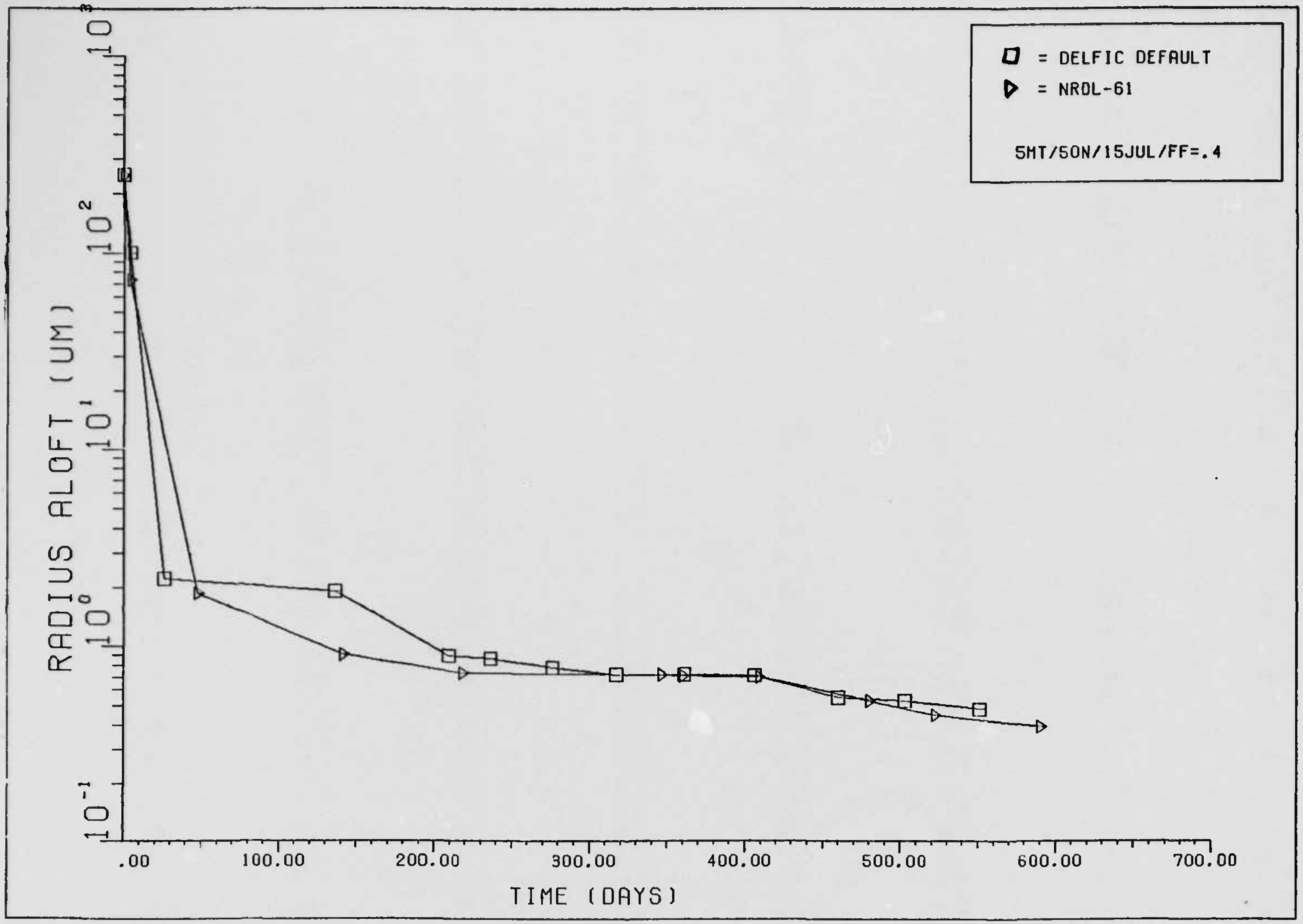

Figure G3. Data Set 2 - Comparison of Radius Aloft (Ra) at Time t

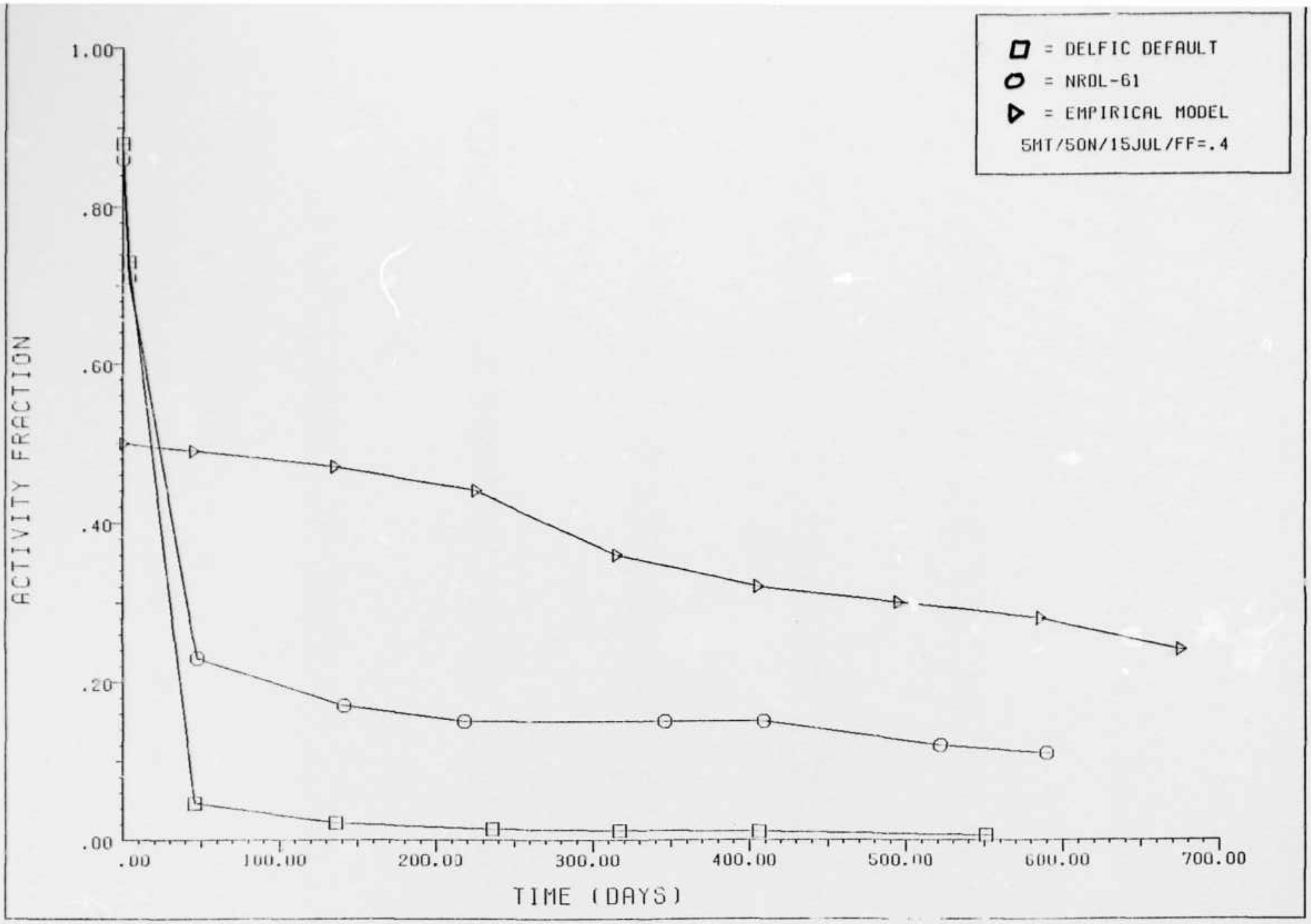

Figure G4. Data Set 2 - Comparison of Activity Fraction Remaining in the Stratosphere at Time t

AD-A154 721 A MODEL FOR WORLD WIDE FALLOUT IN THE NORTHERN HEMISPHERE(U) AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH SCHOOL OF ENGINEERING B GROSNER JAN 85 2/2

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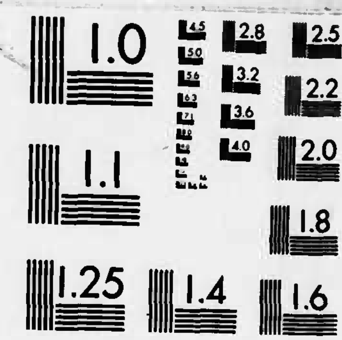

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(cont fr p 92)

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
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18	08		

cont fr p ii

A method is presented to model world wide fallout in the northern hemisphere. The model consists of injecting a radioactive cloud into the stratosphere and allowing it to grow with time. As the cloud reaches the tropopause it is injected to the troposphere using an air mass flux which is a function of latitude and season. The model is dependent on the assumed particle size distribution of the cloud. The model, using two particle size distributions that have been postulated, is compared to an empirical model based on the 1958 nuclear tests of the U.S. and U.S.S.R. Keywords: (to p 91)

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